Orthogonal Polarization Agile Planar Array Antenna

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Abstract

In the recent years, along with the rapid progress of wireless communication technology, wireless equipments have been widely applied to various practical fields such as Global Positioning System (GPS), Wireless Local Networking Systems, and wireless access systems and so on. The main requirements of these wireless equipments are the better performance, low cost and small size.

Due to various functionalities as well as lightness, low profile and easy fabrication properties, microstrip planar antennas are well suited for any wireless equipment. As an important requirement of planar antennas, the polarization agility technique is a typical and good candidate in advanced wireless communication systems because of its promising capability.

In this study, therefore, a novel three conductive layers 2×2 ring-slot array antenna is designed and utilized to realize the simultaneous use of the orthogonal linear polarizations. Due to the use of the characteristics of the ring-slot array antenna and features of the both-sided MIC technology, excellent performances such as broad-band, good isolation, and better cross polarization suppression are obtained. For the symmetrical antenna structure, two orthogonal linear polarizations can be realized with same radiation pattern and same polarization performance. In addition, the antenna design is very simple, and the array antenna is easy to fabricate.

Using the characteristics of the ring-slot array antenna mentioned above, a novel circular polarization ring-slot array antenna with simultaneous use of the orthogonal polarizations is proposed. By integrating a broad-band 90 degrees hybrid circuit, the array antenna can radiate two kinds of circular polarizations; that is, Left Hand Circular Polarization (LHCP) and Right Hand Circular Polarization (RHCP) with good polarization performance. Moreover, the circular polarization can be obtained in a very wide frequency range. The 3 dB axial ratio bandwidths are wider than 25% (RHCP) and 29% (LHCP) and the impedance bandwidth is 47%.

And then a novel linear polarization switchable ring-slot array antenna structure has been developed. Basing on the study of three conductive layers ring-slot array antenna, a Single Pole Double Throw (SPDT) switch circuit is integrated in the array antenna to compose an advanced array antenna, linear polarization switchable array antenna. By using

the SPDT switch circuit, the antenna can provide the switching function between the ϕ = +45 degree and ϕ = -45 degree linear polarization. In this array antenna, ±45 degree linear polarization can be realized with excellent cross polarization suppression better than -20 dB.

Finally, a 90 degrees branch line hybrid circuit and a SPDT switch circuit are integrated in the ring-slot array antenna to form a novel circular polarization switchable ring-slot array antenna. The orthogonal circular polarizations can be switched with simple method. And the orthogonal circular polarization switchable ring-slot array antenna is theoretically and experimentally verified.

These results are very promising and suited for wireless communication systems and RF sensors, which need orthogonal polarization agility.

Publications

International Journal (Refereed)

[1] Sen Feng, Eisuke Nishiyama, Masayoshi Aikawa, “ Broad-band circularly polarized ring-slot array antenna for simultaneous use of the orthogonal polarizations, ” *IEICE TRANS. ELECTRON.*, vol. E93-C, no 7, pp. 1105-1110, July 2010.

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[2] Sen Feng, Eisuke Nishiyama, Masayoshi Aikawa, “ Linear polarization switchable slot ring array antenna with SPDT switch circuit, ” *Proc. of the 2009 Asia-Pacific Microwave Conference (APMC2009),* pp.1828, Singapore, Dec. 2009.

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[2] Sen Feng, Eisuke Nishiyama, and Masayoshi Aikawa, " Polarization switchable slot ring array antenna by using microwave multi layer technology, " *Proc. Of the conference of electronic and electronics engineers in Kyushu*, no. 61, pp. 03-2A-05, 2008.

CONTENTS

Chapter 1

Introduction

1.1 Introduction to Polarization Agile Planar Antenna

Along with the rapid development of wireless communication technology, wireless equipments have been widely applied to various practical fields such as Wireless Local Networking Systems (WLAN), Global Positioning System (GPS), modern communications, Synthetic Aperture Radars (SAR), RF sensors, wireless access systems and so on. The main requirements of these wireless equipments are the better performance, low cost and advanced functions.

Due to various functionalities as well as lightness, low profile and easy fabrication properties, microstrip planar antennas are well suited for any wireless equipment. Moreover, in the present day, applications in wireless systems usually require orthogonal polarization agile and broadband performance in order to meet the miniaturization requirements of mobile units. Thus, orthogonal polarization agile, bandwidth enhancement and advanced functions have become the subjects of great interest to the antenna engineering designers. For these reasons, studies to achieve orthogonal polarization agile and broadband operations of microstrip planar antennas have greatly increased. Much significant progress in the design of microstrip planar antennas with broadband, dual polarization, circular polarization using microwave function circuits or semiconductor devices have reported [1]-[3]. In these papers, antennas are integrated with a function circuit or semiconductor device such as diode, and the integrated planar antenna can realize the polarization agile and broadband performance.

However, these planar antennas are only the development of the single element antenna with polarization agile and broadband performance. The investigation of the array antenna with orthogonal polarization agile and broadband performance has not been involved. In addition, these antennas have the drawback of unsatisfactory performance of the low speed orthogonal polarization switching due to the adjustment of the antenna resonate mode. And the structure of these antennas is relatively complicated. Therefore, it will be very beneficial that the array antenna could be integrated with a high speed, broadband feeding circuit with simple circuit structure.

1.2 Focus of Study

In this study, four kinds of array antennas with polarization agility and wide bandwidth are proposed. Figure 1 shows the basic flow of this thesis.

Firstly, a novel three conductive layers 2×2 ring-slot array antenna is designed and utilized to realize the simultaneous use of the orthogonal linear polarizations. Due to the use of the characteristics of the ring-slot array antenna and features of the both-sided MIC technology, excellent performances such as broad-band, good isolation, and better cross polarization suppression are obtained. For the symmetrical antenna structure, two orthogonal linear polarizations can be realized with same radiation pattern and same polarization performance. In addition, the antenna design is very simple, and the array antenna is easy to fabricate.

Using the characteristics of the ring-slot array antenna mentioned above, a novel circular polarization ring-slot array antenna with simultaneous use of the orthogonal polarizations is proposed. By integrating a broad-band 90 degrees hybrid circuit, the array antenna can radiate two kinds of circular polarizations; that is, Left Hand Circular Polarization (LHCP) and Right Hand Circular Polarization (RHCP) with good polarization performance. Moreover, the circular polarization can be obtained in a very wide frequency range. The 3 dB axial ratio bandwidths are wider than 25% (RHCP) and 29% (LHCP) and the impedance bandwidth is 47%.

Moreover, a novel linear polarization switchable ring-slot array antenna structure has been developed. Basing on the study of three conductive layers ring-slot array antenna, a Single Pole Double Throw (SPDT) switch circuit is integrated in the array antenna to compose an advanced array antenna, linear polarization switchable array antenna. By using the SPDT switch circuit, the antenna can provide the switching function between the ϕ = +45 degree and ϕ = -45 degree polarization. In this array antenna, ±45 degree polarization can be realized with excellent cross polarization suppression better than -20 dB.

In addition, a 90 degrees branch line hybrid circuit and a SPDT switch circuit are integrated in the ring-slot array antenna to form a novel circular polarization switchable ring-slot array antenna. The two kinds of circular polarizations can be switched with simple method. And the orthogonal circular polarization switchable ring-slot array antenna is theoretically and experimentally verified.

These results are very promising and suited for wireless communication systems and RF sensors, which need the orthogonal polarization agility.

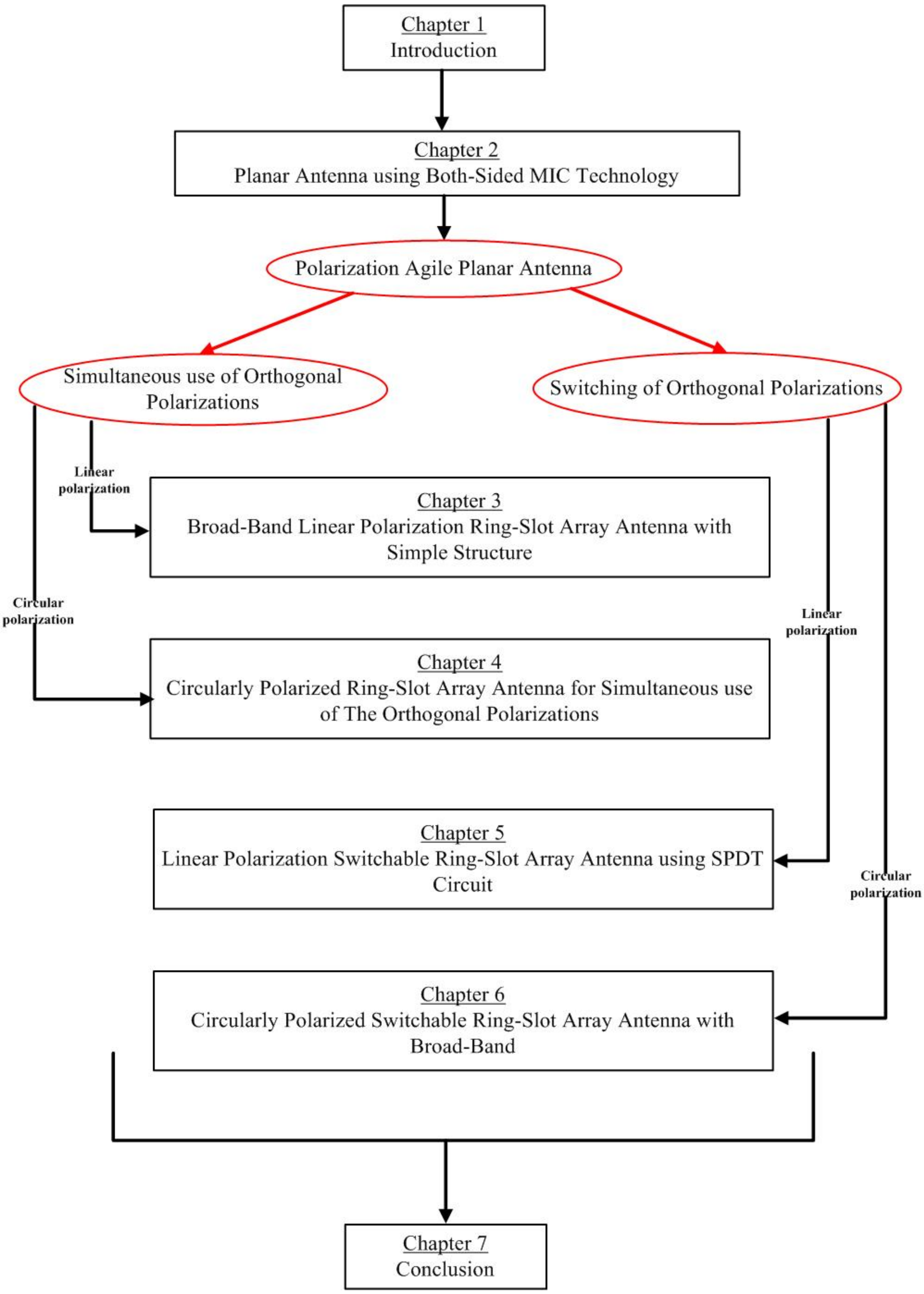


Figure 1 Basic flow of this thesis

Chapter 2

Planar Antenna using Both-Sided MIC Technology

Along with the rapid development of wire less communication technology, microwave planar antennas have been widely applied to various practical fields. Microwave integrated slot array antennas are a vital part of the microwave planar antennas and widely used in the wireless communication equipments. In addition, by the progress of the MIC technology, the researchers [4]-[5] and several other researchers have developed "Both-Sided MIC's technology" which effectively utilizes the several microwave transmission lines on both sides of the substrate. In this chapter, the microwave planar antenna using both-sided MIC's technology is described.

2.1 Microstrip Slot Antenna

Microstrip slot antenna plays an important role in the microwave planar antenna. Microstrip slot antennas are composed of a slot in the ground plane of a substrate and excited by a microstrip line. Many types of slot antennas have been extensively discussed in [6]-[10]. The advantage of these slot antennas is shown as follows:

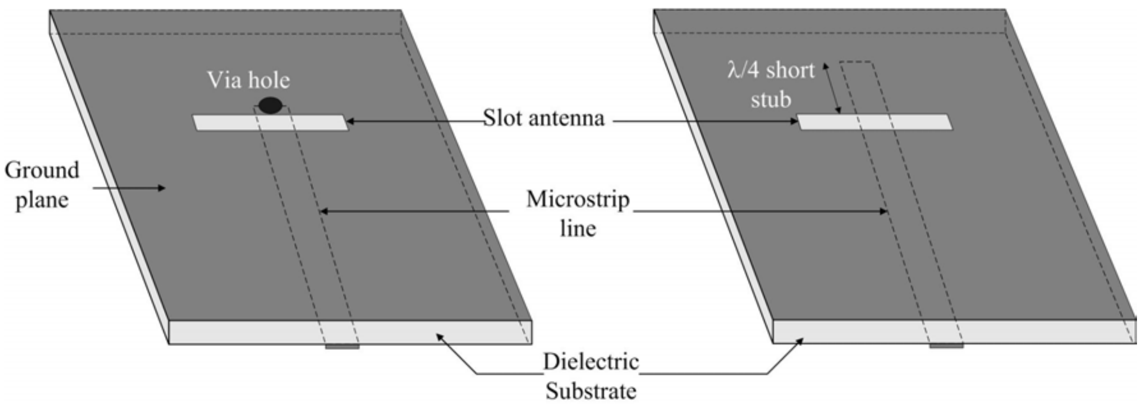
- Slot antennas can produce bidirectional and unidirectional radiation with comparatively wide frequency bandwidth.
- Microstrip line and slot combinations offer an additional degree of freedom in the design of microstrip antennas.
- Slot antennas with desired polarization can be produced, and they are less sensitive to manufacturing tolerances than are microstrip patch antennas.
- Miniaturization potential.

- The antenna design is practically easy.

Basically, there are two kinds of aspects in the design of slot antenna, that is, microstrip fed rectangular slot antenna and the ring slot antenna. The two kinds of slot antennas are described briefly in this section.

Microstrip fed rectangular slot antenna

A microstrip slot antenna is composed of a slot cut in the ground plane of the microstrip line, where the slot is perpendicular to the strip conductor of the microstrip line. The fields of the microstrip line excite the slot. For efficient excitation of the slot, the strip conductor is shorted either through the using of a via hole as shown in Figure 2.1 (a) or through the using of an open circuited stub beyond the edge of the slot as shown in Figure 2.1 (b). A center-fed slot antenna has a very high radiation resistance, and a matching network may be needed to match the antenna to the characteristic impedance of the microstrip line.



(a) (b)

Figure 2.1 Structure of the microstrip fed rectangular slot antenna

This type of slot antennas has been studied theoretically and experimentally by many researchers [11]-[16]. The microstrip fed slot antenna has the advantage of very low cross polarization. In addition, much wider applications can be found if a metallic reflector is added for a directional radiation pattern.

However, due to the antenna structure, this type of slot antenna is difficult to realize the circular polarization.

Ring slot antenna

A ring slot antenna is composed of a circular slot in the ground plane of a dielectric substrate, and fed by a microstrip line as shown in Figure 2.2. This type of slot antenna is very suited for the mobile communications as a vehicular antenna, since it can radiate power at low elevation angles [17].

Using a dual-feed design, the circular polarization can be easily realized from the ring slot antenna. The dual-feed design can be based on a typical hybrid circuit. The ring slot antenna exciting two orthogonal polarization modes by using the dual-feed circuit, and the two modes have same amplitude with 90 degrees phase difference. Moreover, the radiation patterns of the ring slot antenna can be controlled easily by loading the slot with a tunable capacitor [18].

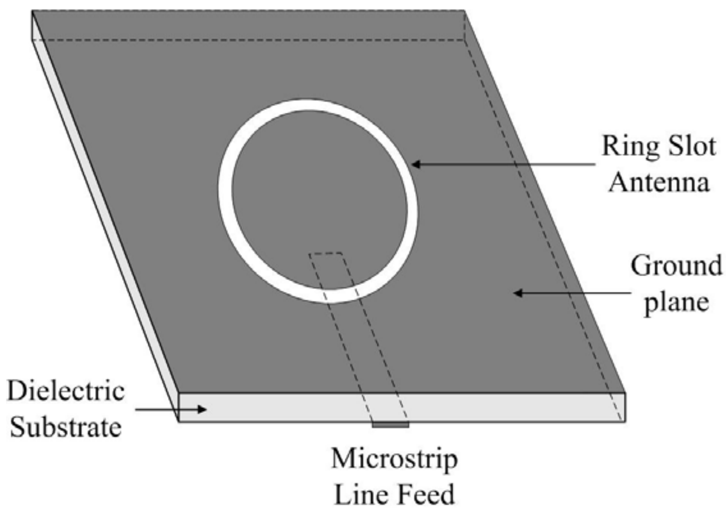


Figure 2.2 Structure of the microstrip fed ring slot antenna

However, most of the ring slot antenna has been discussed with one antenna element so far, and there is no report that investigates ring slot array antennas with circular polarization.

2.2 Antenna Array

In the conventional microstrip antennas, characteristics such as high gain, beam scanning or steering capability are possible only when discrete radiation are combined to form arrays. The elements of an array may be spatially distributed to form a linear, planar, or volume array. A linear array consists of elements located finite distances apart along a straight line. A planar array has elements distributed on a plane and a volume array has elements that are distributed in three dimensions.

In this section, two kinds of the most usefully array, that is, the one-dimensional parallel feed array and the two-dimensional parallel feed array are described.

One-dimensional parallel feed array

Figure 2.3 shows the fundamental configuration of a one-dimensional parallel feed array.

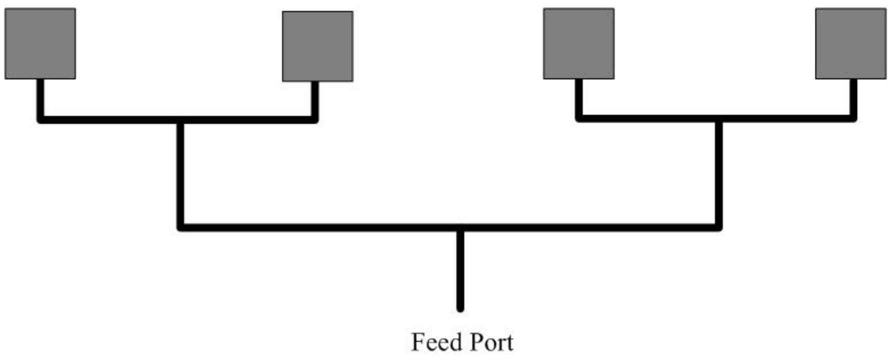


Figure 2.3 One-dimensional parallel feed array

This array consists of branching networks of two way power dividers. A corporate feed is the most widely used parallel feed configuration. In this parallel feed array, the power is divided equally at each junction. However, different power divider ratios can be chosen to generate a tapered distribution across the array. If the distances from the input port to each radiating element are identical, the beam position is independent of the frequency and the feed is broadband.

In this type of array, basically, the T-junction or its modified configuration is used as a power divider. The quarter-wave transformers are generally utilized to obtain impedance match at the junction.

Two-dimensional parallel feed array

The configuration of two-dimensional parallel feed array is shown in Figure 2.4. The basic configuration can be extended to large arrays with specifically 2^n elements per side to maintain a symmetrical configuration. Some works on application of this type of array have been presented [19]-[20].

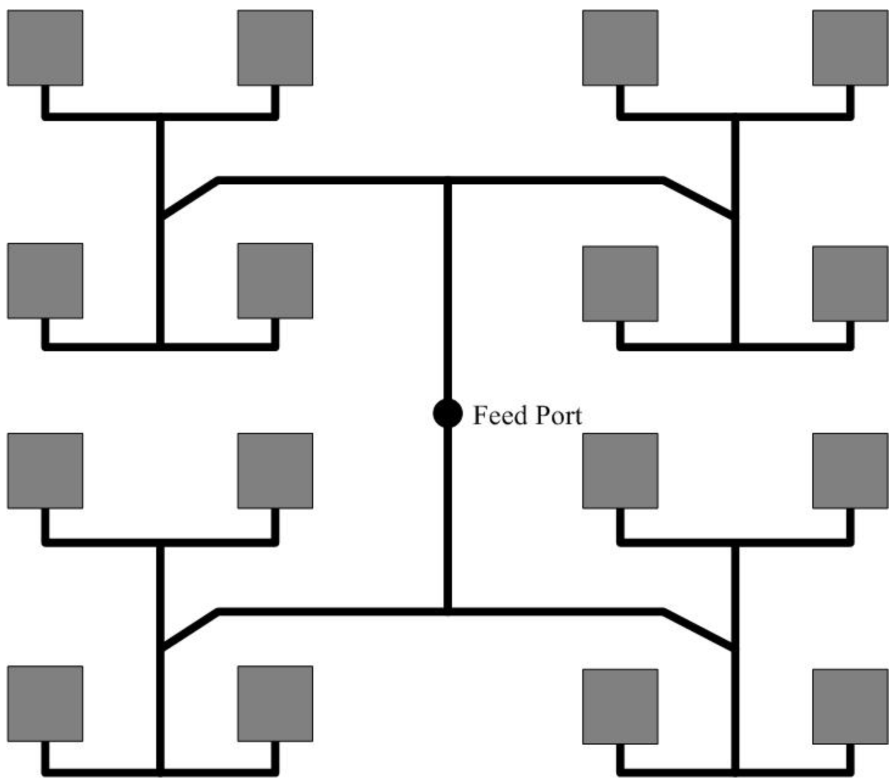


Figure 2.4 Two-dimensional parallel feed array

2.3 Polarization

Antenna can radiate three kinds of polarizations, that is, linear, elliptic, or circular polarizations. If the path of the electric field vector is back and forth along a line, it is said to be linearly polarized. As Figures 2.5 (a) and (b) shows, in actual space above the earth, if the electric vector is vertical or lies in a vertical plane, the wave is said to be vertically polarized; if the electric vector lies in a horizontal plane, the wave is said to be horizontally polarized. If the electric field vector remains constant in length but rotates around in a circular path, it is circularly polarized. The rotation radian frequency is ω and occurs in one of two directions, referred to as the sense of rotation. If the wave is traveling toward the observer and the vector rotates counterclockwise, it is right-hand polarization. If it rotates clockwise, it is left-hand polarization. Right-hand and left-hand circularly polarized waves are shown in Figures 2.5 (c) and (d). A circularly polarized wave can be realized when two linearly polarized waves are combined, that is, if they are simultaneously launched in the same direction from the same antenna-provided that the two linear polarization are at right angles to each other and their phase difference is 90 degrees. The right-hand or left-hand rotation depends on whether the phase difference is 90 degrees or -90 degrees. Moreover, for circular polarization it is necessary also that the two linearly polarized components by equal amplitude. Finally, a wave may be elliptically polarized, with either right- or left-hand sense of rotation, as shown in Figures 2.5 (e) and (f).

A general polarization ellipse is shown in Figure 2.6 with a reference axis system, where the wave associated with this polarization ellipse is traveling in the +z-direction. The sense of rotation can be either left or right. The instantaneous electric field vector ε has components ε_x and ε_y along the x and y axes. The peak values of these components are E_1 and E_2. The angle γ describes the relative values of E_1 and E_2 form

$$\gamma = \tan^{-1}\left(\frac{E_2}{E_1}\right) \qquad 0^\circ \le \gamma \le 90^\circ \tag{2.1}$$

The tilt angle of the ellipse, τ, is angle between the x-axis (horizontal) and the major axis of the ellipse. The angle ω' is seen from Figure 2.6 to be

$$\omega' = \cot^{-1}(AR) \qquad 1 \le |AR| \le \infty \qquad -45^\circ \le \omega' \le 45^\circ \tag{2.2}$$

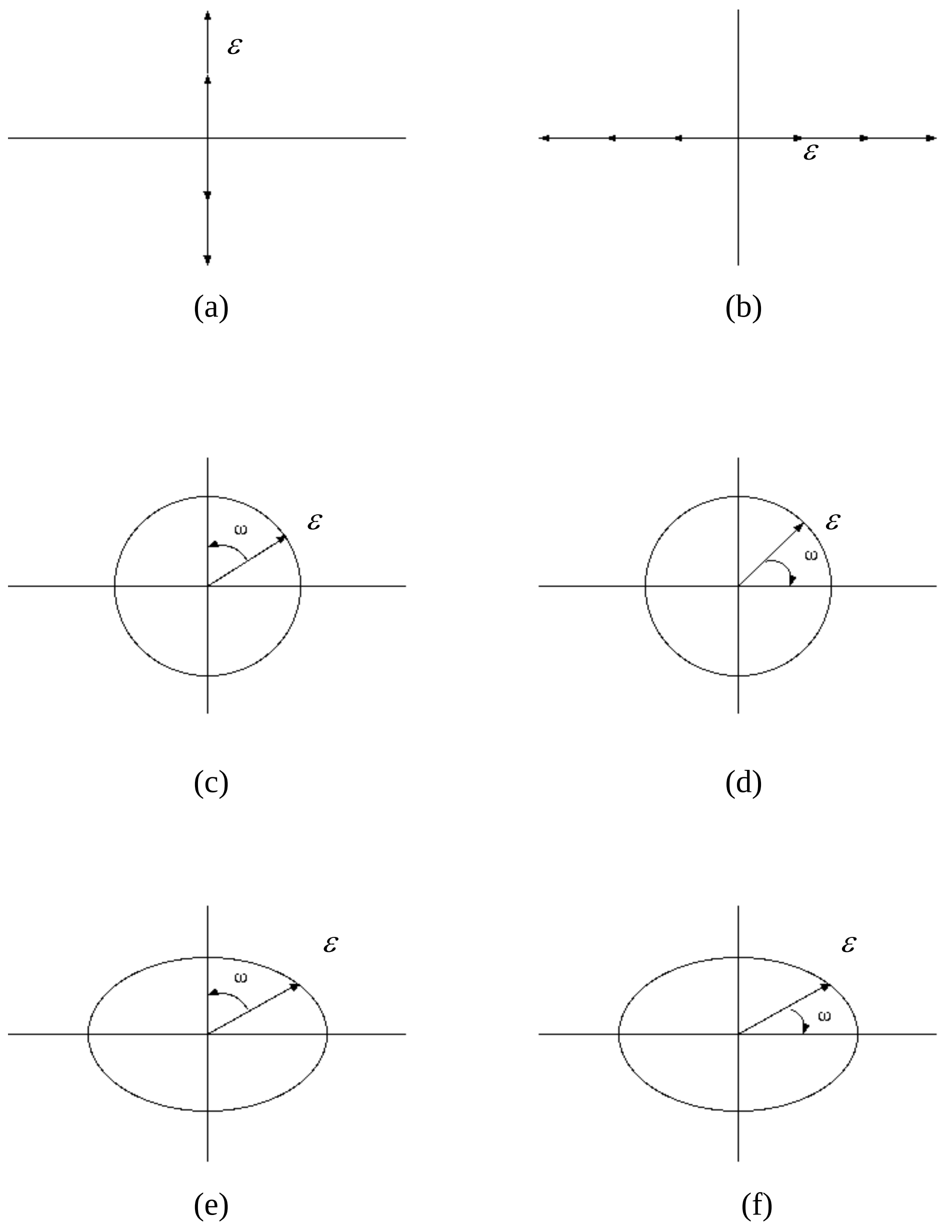


Figure 2.5 Polarization states. The wave is approaching. (a) Linear (vertical) polarization. (b) Linear (horizontal) polarization (c) Right-hand circular polarization. (d) Left-hand circular polarization. (e) Right-hand elliptical polarization (f) Left-hand elliptical polarization

The axial ratio of the ellipse |AR| is the ratio of the major axis (OA) electric field component to the minor axis (OB) electric field component, where

$$OA = \left[\frac{1}{2} \{ E_1^2 + E_2^2 + [E_1^4 + E_2^4 + 2 E_1^2 E_2^2 \cos(2\delta)]^{1/2} \} \right]^{1/2} \quad (2.3)$$

$$OB = \left[\frac{1}{2} \{ E_1^2 + E_2^2 - [E_1^4 + E_2^4 + 2 E_1^2 E_2^2 \cos(2\delta)]^{1/2} \} \right]^{1/2} \quad (2.4)$$

The sign of AR is positive for left-hand sense and negative for right- hand sense.

The instantaneous electric field for the wave of Figure 2.6 can be written as (with z = 0 for simplicity)

$$\varepsilon = \varepsilon_x \hat{x} + \varepsilon_y \hat{y} = E_1 \cos(\omega t)\hat{x} + E_2 \cos(\omega t + \delta)\hat{y} \quad (2.5)$$

Where δ is the phase by which the y-component leads the x-component, and the $\hat{x}$, $\hat{y}$ are the radial unit vectors. This representation describes the ellipse shape as time progresses.

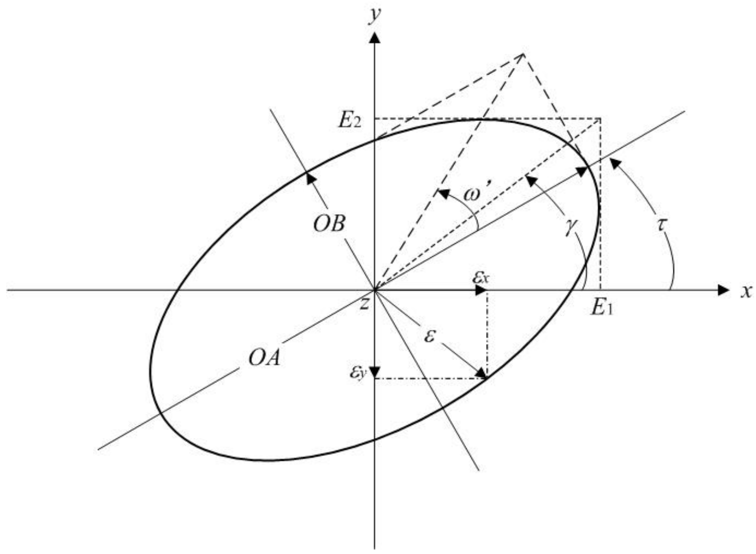


Figure 2.6 The general polarization ellipse. The associated wave direction is out of the page in the +z-direction. The tip of the instantaneous electric field vector ε traces out the ellipse

Linear Polarization

If the components are in phase (δ =0) the net vector is linearly polarized. The orientation of the linear polarization depends on the relative values of E_1 and E_2. For example, if E_1= 0 vertical linear polarization results; if E_2 = 0 horizontal linear results.

By summarize the linear polarization; this kind of polarization can be accomplished if the field vector (electric or magnetic) possesses:

a. Only one component

b. Two orthogonal linear components that are in phase or 180° (or multiples of 180°) out of phase.

Elliptical Polarization

If $E_1 = E_2$, the polarization is linear at 45° with respect to the axes. Linear polarization is a collapsed ellipse with infinite axial ratio. If δ is nonzero, the axial ratio is finite. When $\delta > 0$, $\mathcal{E}_y$ leads $\mathcal{E}_x$ in phase and the sense of rotation is left hand. For $\delta < 0$ the sense is right hand.

The necessary and sufficient conditions to accomplish elliptical polarization are if the field vector (electric or magnetic) possesses all of the following:

a. The field must have two orthogonal linear components.

b. The two components can be of the same or different magnitude.

c. (1) If the two components are not of the same magnitude, the time-phase difference between the two components must not be 0°or multiples of 180° (because it will then be linear). (2)If the two components are of the same magnitude, the time-phase difference between the two components must not be odd multiples of 90° (because it will then be circular).

Circular Polarization

If $E_1 = E_2$ and $\delta = \pm 90°$, the polarization is circular (+ 90° is LHCP, and -90° is RHCP). The axial ration or a circularly polarized wave is unity.

The necessary and sufficient conditions to accomplish circular polarization are if the field vector (electric or magnetic) possesses all of the following:

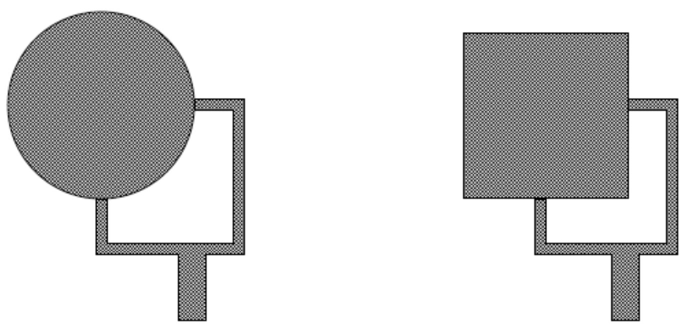
a. The field must have two orthogonal linear components.
b. The two components must have the same magnitude.
c. The two components must have a phase difference of odd multiples of 90° .

2.4 Circularly Polarized Antenna

It is usually designed for single-mode operation that radiates mainly linear polarization. For radiating a circular polarization, an antenna must support orthogonal fields of equal amplitude with 90° phase difference. This requirement can be accomplished by a single patch with proper excitations or by a patch array with an appropriate arrangement and phasing.

Two Fed Circularly Polarized Antenna

The fundamental configurations of a two fed circularly polarized patch using an external power divider are shown in Figure 2.7.



(a) Circular patch (b) Square patch

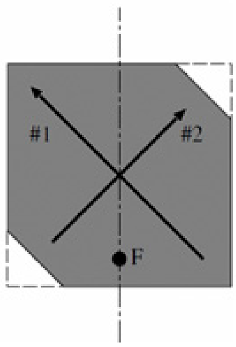
Figure 2.7 Typical configurations of two-fed circularly polarized microstrip antennas

The antenna patch is usually square or circular. The dual-orthogonal feeds excite two orthogonal modes with equal amplitude with 90° phase difference. Several power divider circuits that have been successfully employed for CP generation include the quadrature hybrid, the ring hybrid, the Wilkinson power divider, and the T-junction power splitter [21]. The power divider circuit divides the input RF signal into two outputs with equal amplitude and 90 degrees phase difference.

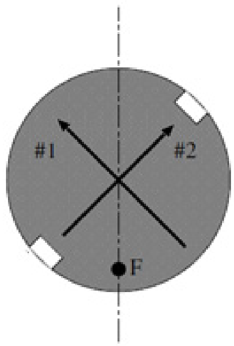
Singly Fed Circularly Polarized Antenna

Typical configurations for singly fed CP microstrip antennas are shown in Figure 2.8. A single-point feed patch capable of producing CP radiation is very desirable in situations where it is difficult to accommodate dual-orthogonal feeds with a power divider network. Because a patch with a single-point feed generally radiates linear polarization, in order to radiate CP, it is necessary for two orthogonal patch modes with equal amplitude and with 90° phase difference to be induced. This can be accomplished by slightly perturbing a patch at appropriate locations with respect to the feed.

The singly fed circularly polarized microstrip antennas operate on the principle of detuning degenerate modes of a symmetrical patch by perturbation segments as shown in Figure 2.9. The fields of a singly fed patch can be resolved into two orthogonal degenerate modes, #1 and #2. Proper perturbation segments will detune the frequency response of mode #2 such that, at the operating frequency f_0, it is the same amplitude and 90 degrees phase difference with respect to mode #1. Therefore, the two modes satisfy the required condition for CP radiation. The detail explanation is done in [22]-[24].



(a) Square patch



(b) Circular patch

Figure 2.8 Typical configurations of singly fed circularly polarized microstrip antennas

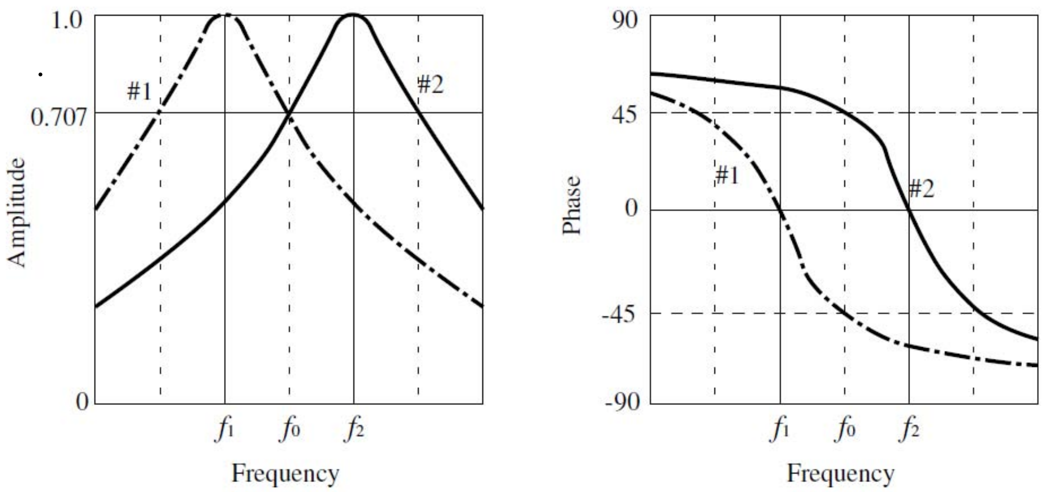


Figure 2.9 Amplitude and phase of orthogonal modes for singly fed circularly polarized microstrip antennas.

The axial ratio is the key characteristic to the circular polarization. The ratio of the major axis to the minor axis is referred to as the axial ratio (AR). The axial ratio is generally used to specify the quality of the circularly polarized waves. As shown in Figure 2.6, the axial ratio is equal to

$$AR = \frac{(Major \ \ axis)}{(Minor \ \ axis)} = \frac{OA}{OB} \quad , \qquad 1 \le AR \le \infty \qquad (2.6)$$

In general, the unit of axial ratio is dB ($10\log_{10}|AR|$). In a pure circular polarization, the AR is 1 or 0 dB.

2.5 Both-Sided MIC Technology

2.5.1 Features of Both-Side MIC Technology

The both-sided MIC's technology has many practical advantages due to the effects of combining several kinds of transmission lines, and the effective use of both sides of the substrate. The advantages are as follows:

Excellent Circuit Functions;

1. According to integrate a number of transmission line transitions such as microstrip line and the slot line as shown in Figure 2.1, series branch circuit and parallel branch circuit are easily realized. Two branch circuits are very useful for Both-sided MIC circuits.
2. The orthogonal transmission lines are easily constructed using the “even/odd transition modes”.
3. A very tight line coupling is also achieved without any difficulty.

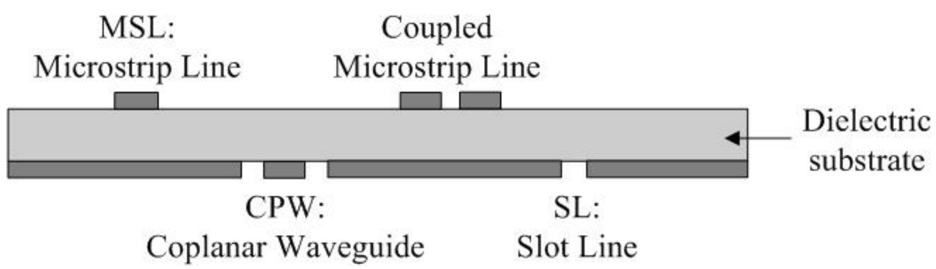


Figure 2.10 Planar transmission lines used in microwave integrated

Great Design Flexibility;

1. Higher integration can be achieved by using both sides of the substrate effectively.
2. Active or passive devices are easily mounted in series with, or parallel to, transmission lines, because the Both-Sided MIC’s use coplanar type lines such as slot lines or coplanar waveguides.
3. A very wide range of transmission line impedance is available.
4. Line crossings can be eliminated even in a comparatively complicated circuit such as a double-balanced mixer [25].

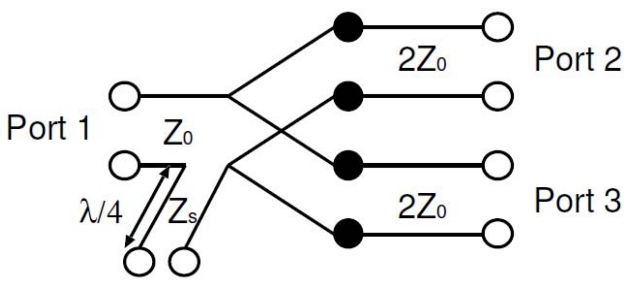
2.5.2 Branch Circuit using Both-Sided MIC Technology

There are two kinds of branch circuits using both-Sided MIC technology are described in this section, that is, microstrip-slot branch circuit and the slot-microstrip branch circuit. Because of the using of the both-Sided MIC technology, the branch circuits have no bent lines and are composed of only straight and short lines, the feeding loss and the radiation loss can be expected to be small.

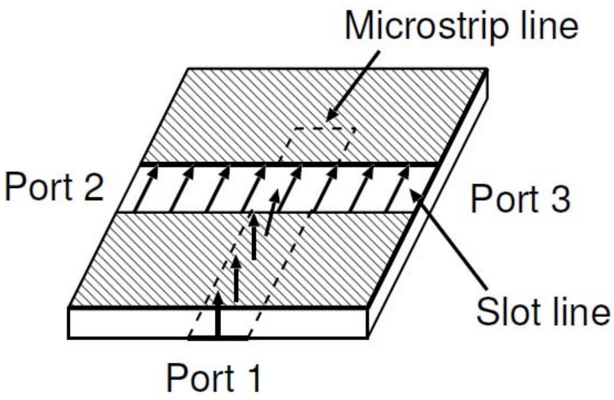
Microstrip-slot Branch Circuit

The microstrip-slot branch circuits are composed of microstrip line on a surface and a slot line on the reverse plane. The configuration and the equivalent circuit are shown in Figure 2.11.

The microstrip-slot branch circuit is a parallel power divider. At the equal distance points from the branch point on the slot line, two divided signals have the same amplitude and are in phase in a very wide band.



(a) Equivalent circuit

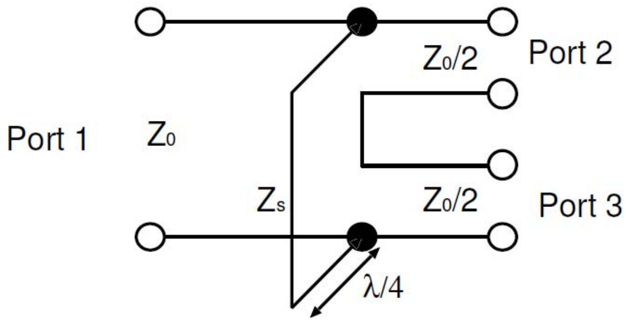


(b) Configuration of microstrip-slot branch circuits

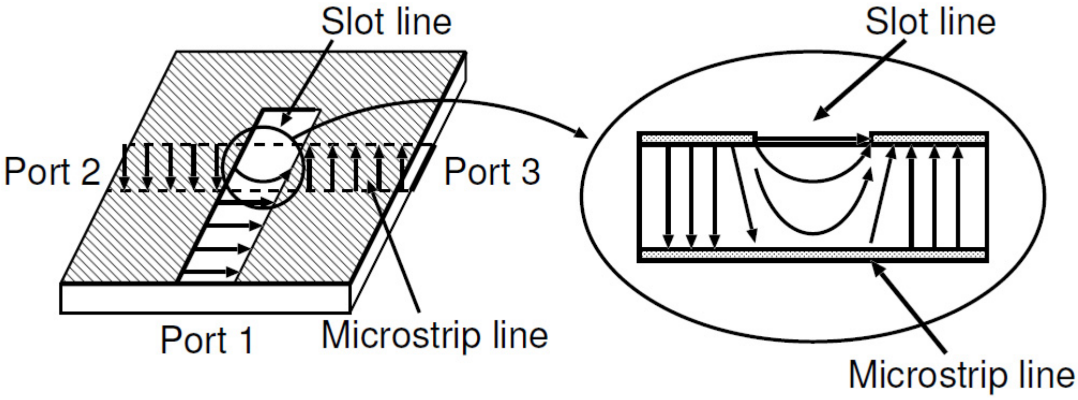
Figure 2.11 Microstrip-slot branch circuits

Slot-microstrip Branch Circuit

Figure 2.12 shows the configuration and equivalent circuit for a slot-microstrip branch circuit. The slot-microstrip branch circuit is a series power divider. At the equal distance points from the branch point on the microstrip line, two divided signals have the same amplitude and are out of phase in a very wide band.



(a) Equivalent circuit



(b) Configuration of slot-microstrip line

Figure 2.12 Slot-microstrip branch circuits

2.5.3 Comparing a Conventional Antenna with an Antenna Using Both-Sided MIC Technology

Feed circuits for conventional microstrip array antennas have been usually composed of the microstrip-line (Figure 2.13). In this case, since all the feeding circuits are connected in parallel, many matching circuits are required. As a result, the feeding circuit layout for the array antennas become complicated and the length of the feed lined become much longer. Those cause the array antennas to increase the feeding loss as well as an undesired radiation.

A microstrip array antenna by using Both-Sided MIC technology is shown in Figure 2.14. By using the Both-Sided MIC technology for the feeding circuits, the array antenna needs no impedance matching circuits and has very simple circuit configuration, which are mainly due to the excellent performances of both the microstrip-slot parallel branch circuit and the slot-microstrip series branch circuit. And the feeding loss and the radiation loss can be expected to be small because for the feeding circuits have no bent lines and are composed of only straight and short lines.

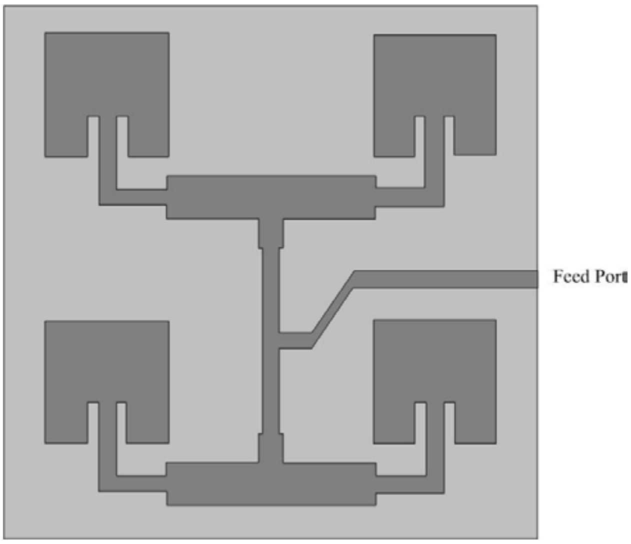


Figure 2.13   Conventional microstrip array antenna.

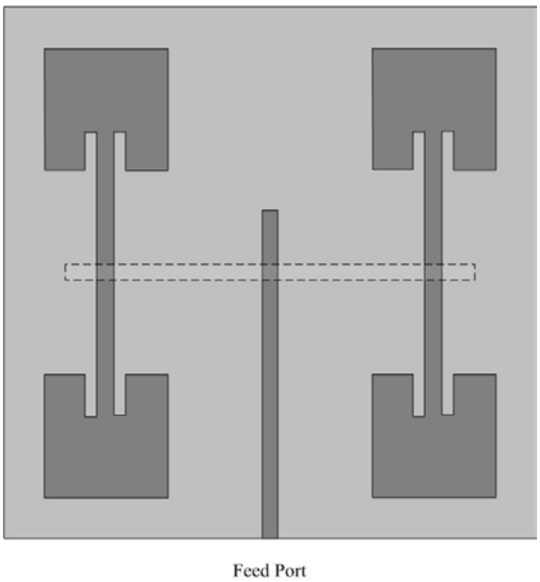
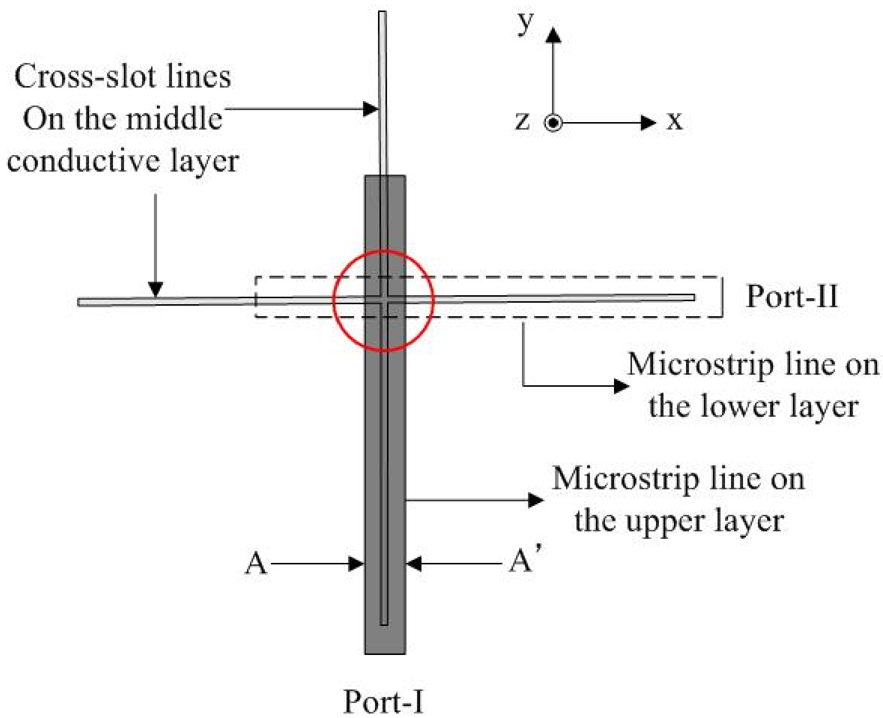


Figure 2.14   Microstrip array antenna using Both-Sided MIC technology

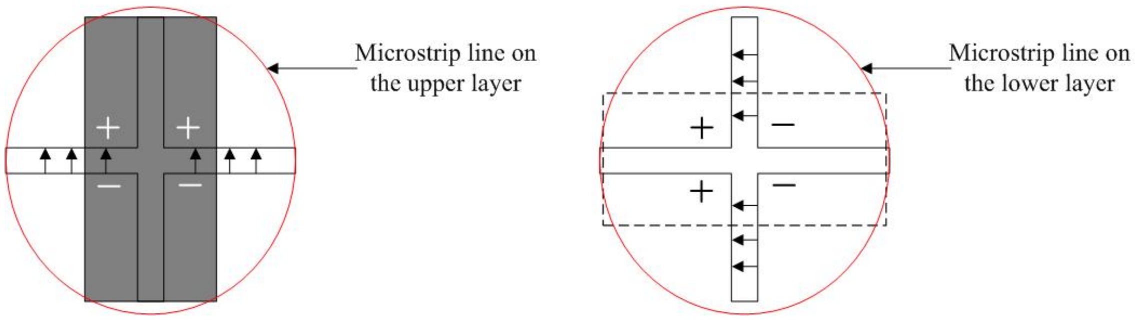
2.5.4 Three Layers Orthogonal Resonating Feed Circuit using Both-Sided MIC Technology

Using the Both-sided MIC technology, a three layers orthogonal resonating feed circuit is proposed. Figure 2.15 (a) shows the configuration of the three layers feed circuit, which consist of two layer dielectric substrates, three conductive layers and two input ports. The upper feed circuit is constructed with Port-I and microstrip line on the upper layer. The lower feed circuit is constructed with Port-II and microstrip line on the lower layer. The cross slot lines on the middle layer are the dual-use for both the upper feed circuit and the lower feed circuit.

When a RF signal is fed to the feed circuit from Port-I / Port-II, the signals are divided in parallel (in phase) to the two cross-slots by the upper feed circuit / lower feed circuit. Using the microstrip-slot branch circuit, the RF signal is fed to the slot line which perpendicular to the feed microstrip line. Since the RF signals in the slot line are in phase as shown in Figure 2.15 (b), the cross slot line which parallel to the feed microstrip line is not be excited in principle.



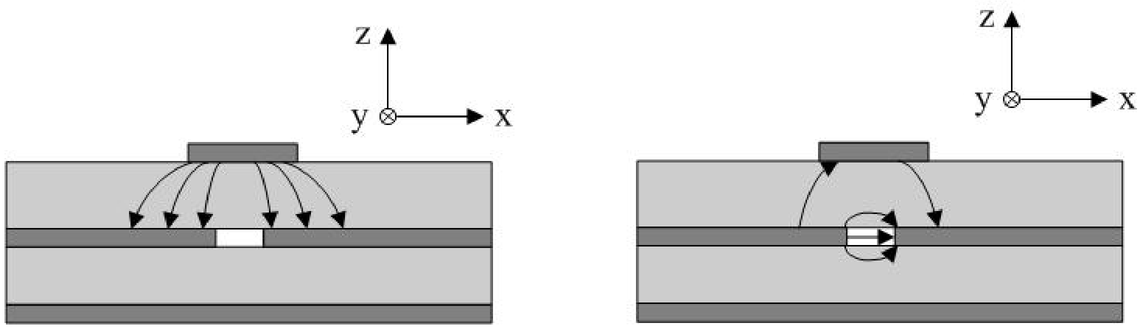
(a)



Fed by Prot-I

Fed by Port-II

(b)



Even mode transmission (A-A')

Odd mode transmission (A-A')

(c)

Figure 2.15 Configuration of the three layers orthogonal resonating feed circuit

In addition, there are two ways of exciting the three layers feed circuit, that is, even mode transmission and the odd mode transmission as shown in Figure 2.15 (c). The two kinds of transmission modes are orthogonal to each other.

Therefore, the excellent isolation performance between the two feed pots of the proposed three layers feed circuit based on the both-sided MIC technology can be obtained.

Chapter 3

Broad-Band Linear Polarization Ring-Slot Array Antenna with Simple Structure

3.1 Introduction

Modern wireless communication systems, such as those for satellite for satellite links (GPS, vehicular, etc.), for mobile communication, and for emerging applications, such as wireless local-area networks (WLANs), often require compact antennas at low cost. Further, due to their various functionalities as well as lightness, low profile and easy fabrication properties, microwave planar antennas are well suited for airborne applications, such as synthetic aperture radar (SAR) systems.

Therefore, the microwave slot antennas are attracting much attention in various wireless communication systems due to their miniaturization potential, wide band and low cost recently. In addition, dual polarization operation is an important subject in slot antenna design. Several microwave slot antennas are reported to achieve improved performance, particularly for broadband and dual polarization applications. In [26]-[27], microwave slot antennas are reported to obtained broadband polarization. In [28]-[29], dual polarization is obtained by a feed network and two ports.

In this chapter, a novel broad-band linear polarization ring-slot array antenna is described. The two orthogonal linear polarizations can be realized simultaneously by using proposed antenna. The both-sided MIC technology as mentioned in last chapter is effectively employed in forming this proposed slot array antenna. By using this technology, an excellent isolation between two input ports and very simple circuit configuration is achieved.

As a fundamental research of ring-slot array antenna, the simulated and measured characteristics of the proposed array antenna are described in this chapter. And both the simulation results and the experimental results show that the proposed array antenna has good polarization characteristics for the two orthogonal linear polarizations.

3.2 Antenna Design Procedure and Simulation

The structure of the proposed broad-band linear polarization ring-slot array antenna is shown in Figure 3.1. The proposed antenna is constructed with 2 layer dielectric substrates, conductive 3 layers and two input port (Port-I and Port-II). The microstrip

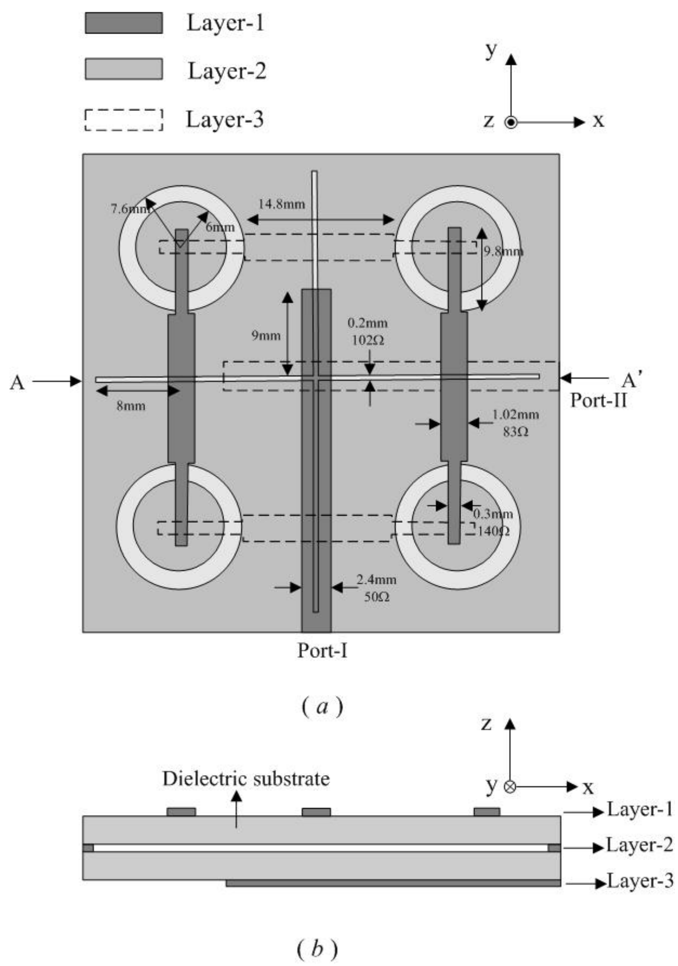


Figure 3.1 The structure of the proposed 2×2 ring-slot array antenna
(a) Top view, (b) Side view (A-A')

lines are on layer-1 and layer-3. The 2×2 ring-slot antenna elements and slot lines are on layer-2. The four ring-slot antenna elements are excited orthogonally by the orthogonal feed circuits on the three layers. The upper feed circuit is constructed with Port-I and microstrip line on the layer-1. The lower one is constructed with Port-II and microstrip line on the layer-3.

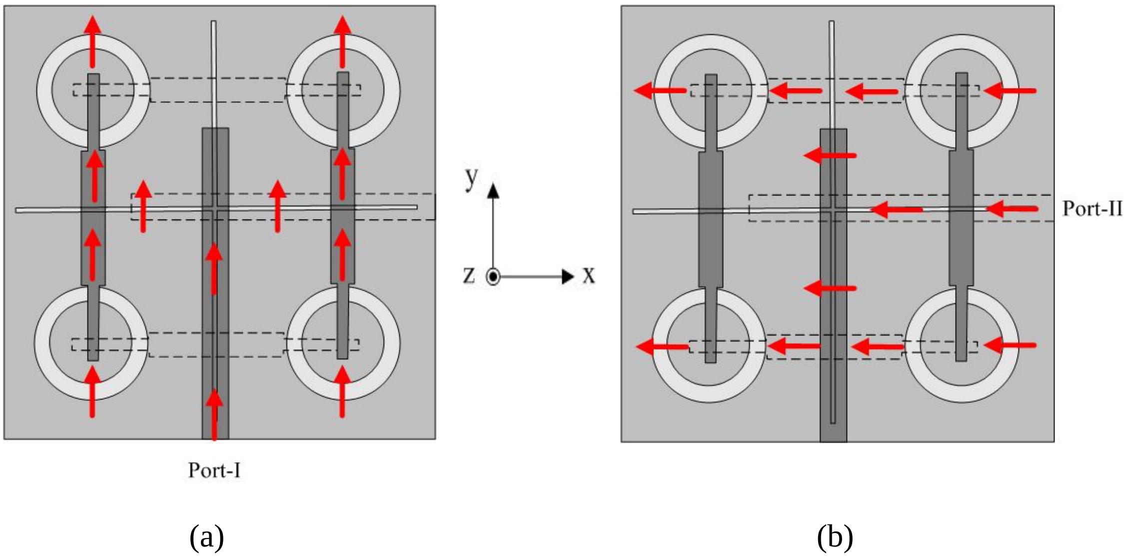


Figure 3.2 Schematic electric field of the feed circuit
(a) Upper feed circuit (b) Lower feed circuit

Figure 3.2 (a) and (b) show the schematic electric fields fed by Port-I and Port-II, respectively. The ring-slot array antenna has a very simple circuit configuration, which is mainly due to the excellent performance of both the microstrip-slot parallel branch circuit and the slot-microstrip series branch circuit [30] - [31]. When a RF signal is fed to the feed circuit (Port-I or Port-II), the signal is divided in parallel (in phase) to the cross-slot by the strip-slot branch circuit, and then they are divided in series (out of phase) to the microstrip lines connected to the ring-slot antenna elements through the slot-strip branch circuit. As Figure 3.2 shows, the structures of the two feed circuits (the upper feed circuit and the lower feed circuit) are orthogonal to each other. When the input port is Port-I, the RF signal is fed to the upper feed circuit, the linear polarization can be realized to *y* axis; When the input port is Port-II, the linear polarization can be realized to *x* axis. Therefore, the two orthogonal linear polarizations can be realized easily.

The simulator Ansoft HFSS is used for designing and analyzing the proposed ring-slot array antenna shown in Figure 3.1. In the simulation, the relative dielectric constant of substrate ε_r is 2.15 and the thickness is 0.8 mm. The design frequency is 7.5 GHz. The size of antenna ground plane is 60 mm × 60 mm. The RF signals are fed to Port-I and Port-II microstrip lines with 2.4 mm width. The characteristic impedance of the feed microstrip lines and the slot lines are 50 Ω and 102 Ω, respectively. The characteristic impedance of microstrip lines connected to the ring-slot antennas is 83 Ω for the impedance matching. The length and width of the ring-slot are 48 mm which is a guided wave length λ_g at the design frequency of 7.5 GHz and 1.6 mm, respectively.

Figure 3.3 shows the S-parameters of the proposed ring-slot antenna array. The isolation between two input ports is better than -30 dB, the return loss both Port-I and Port-II are better than -10 dB in the frequency range of 6 GHz to 7.8 GHz, and the relative bandwidth of the return loss for better than -10 dB is 26%.

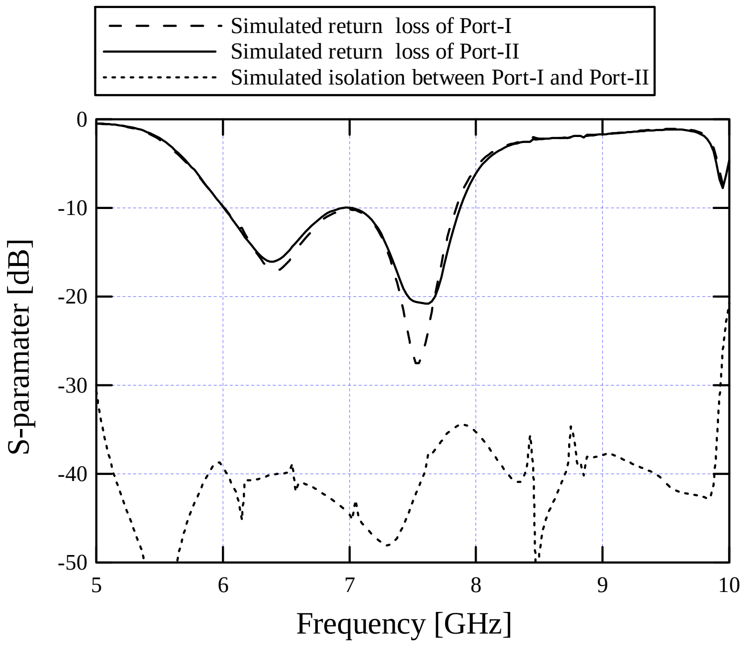
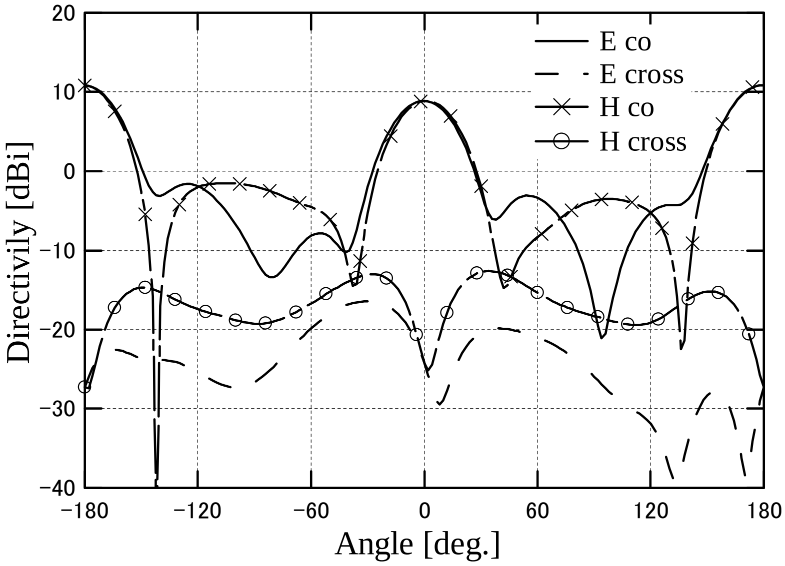
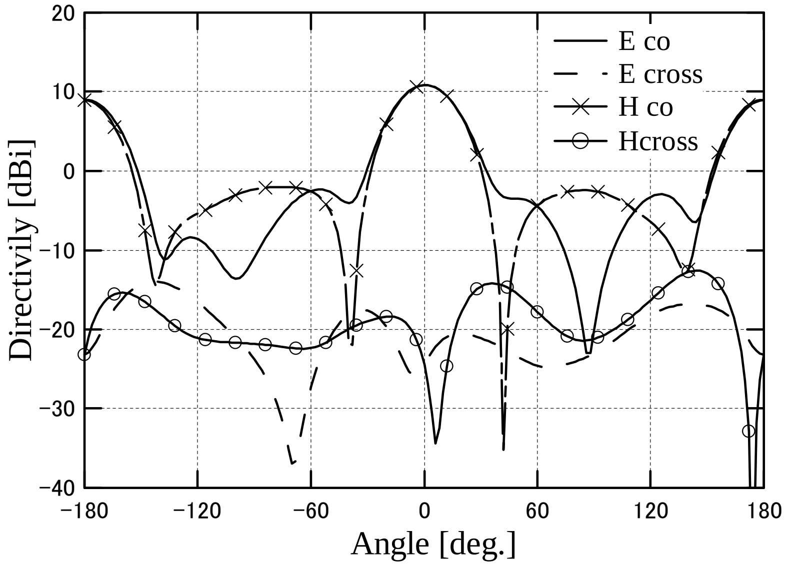


Figure 3.3 Simulated return loss and isolation of the array antenna

By this result, the broad-band ring-slot array antenna for simultaneous use of orthogonal linear polarizations is confirmed. The excellent isolation of two input ports better than -30 dB is obtained mainly due to no electric interferes between the microstrip-lines and the slot lines in the feed circuit. The broad impedance bandwidth and simple antenna structure are obtained mainly due to the orthogonal feed circuits realized by the use of Both-Sided MIC technology.



(a)



(b)

Figure 3.4 Radiation pattern at 7.5 GHz

(a) Excited by Port-I

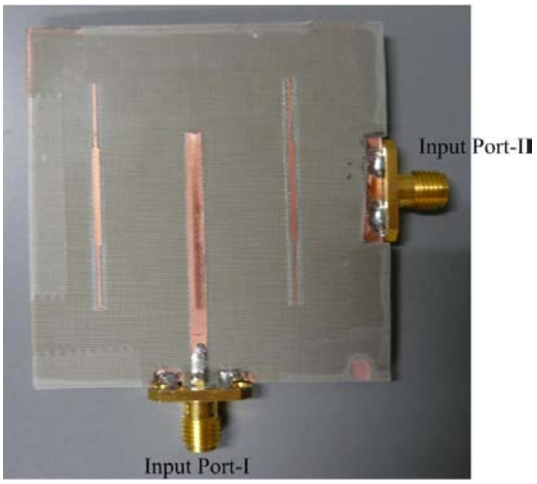
(b) Excited by Port-II

The far field of the 2×2 ring-slot antenna array is also simulated by HFSS. Figure 9 shows the radiation patterns of the proposed ring-slot antenna array. When the RF signal is fed to Port-I, the directivity for linear polarization (*y* plane) of the proposed array antenna is shown in Figure 3.4 (a). The gain in the boresight direction is 9.92 dBi at 7.5 GHz. The cross polarized radiation on both the E-plane and H-plane are better than -20 dBi. The excellent suppression is mainly due to the symmetrical and balanced arrangement of feed circuits. When the RF signal is fed to Port-II, the directivity for linear polarization (*x* plane) of the proposed array antenna is shown in Figure 3.4 (b). The same polarization performance is obtained due to the symmetrical feed circuits.

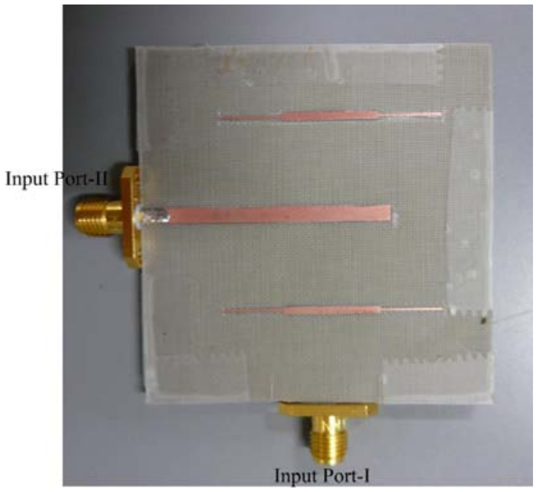
As a result, the broad-band linear polarization ring-slot array antenna with simple structure is theoretically confirmed.

3.3 Experimental Results and Discussion

The array antenna is fabricated on a Teflon Glass Fiber substrate with the relative dielectric constant of $\varepsilon_r = 2.15$. The thickness of the structure is 0.8 mm. The photo of this fabricated antenna is shown in Figure 3.5. The antenna size is 60 mm×60 mm. The

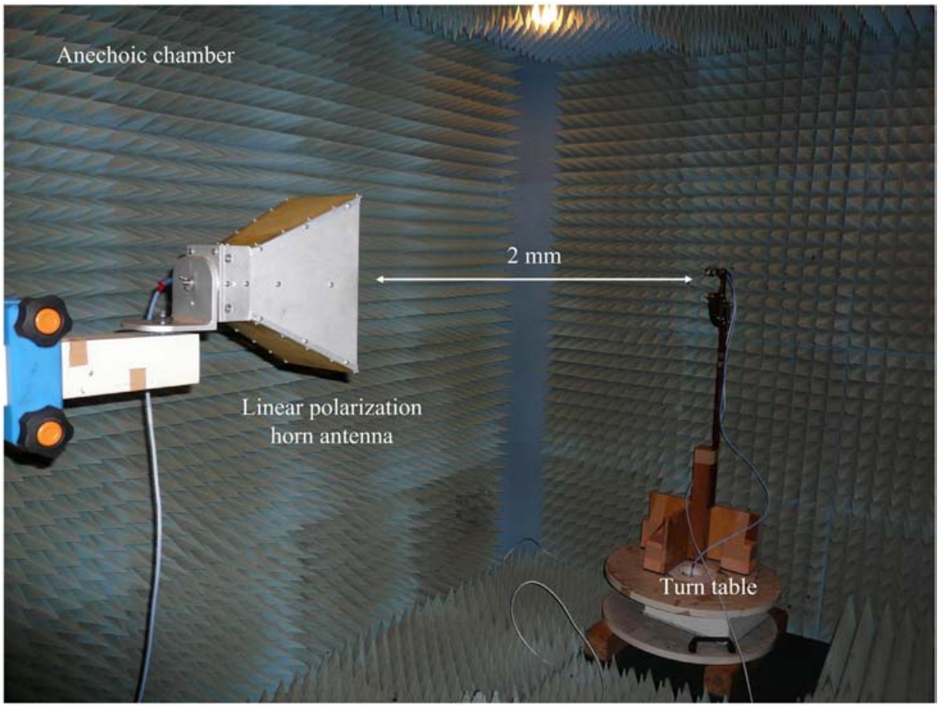


Obverse side

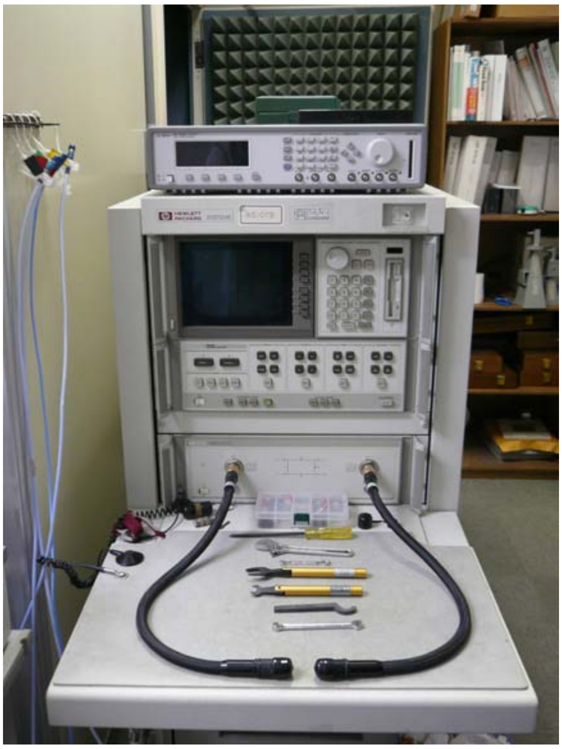


Reverse side

Figure 3.5 Photograph of the fabricated ring-slot array antenna



The anechoic chamber



Network Analyzer 8510C (Agilent)

Figure 3.6 Photograph of the experimental equipments antenna performance is measured through the experiment using an Agilent Network Analyzer 8510C in an anechoic chamber. A linear polarization horn antenna is used to measure the proposed antenna. The horn antenna is set at a distance of 2m from the proposed antenna. The antenna is located on a turn table. The photos of the experimental equipments are shown in Figure 3.6.

Figure 3.7 shows the S-parameters of the antenna. The isolation between two input ports is better than -30 dB. The measured return loss of both the Port-I and the Port-II are better than -10 dB in the frequency range over 6.5 GHz to 8.1 GHz. The broadband performance is obtained in the measurement.

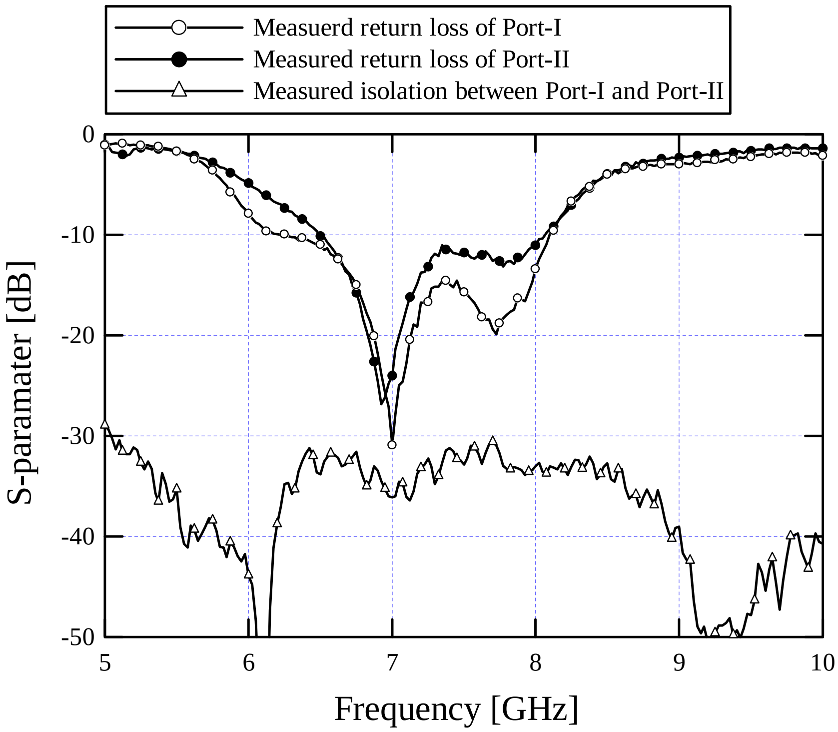
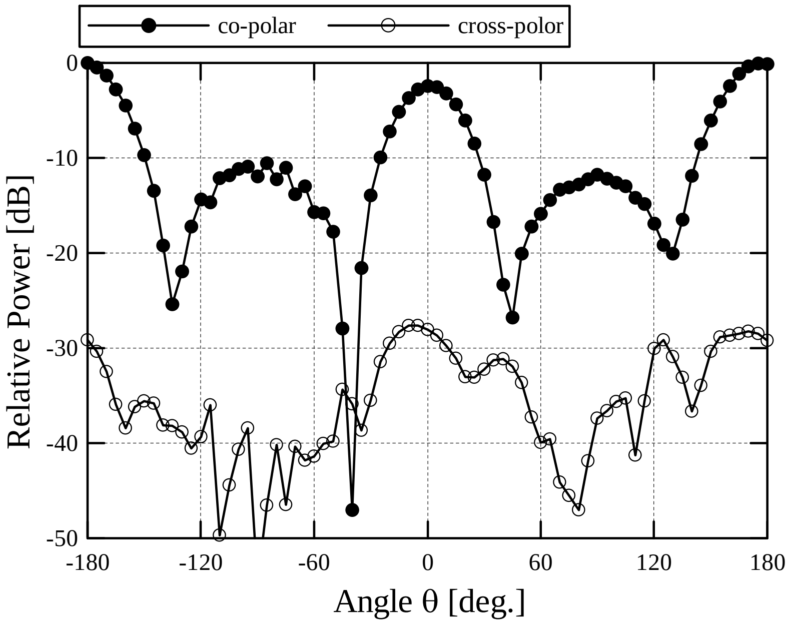
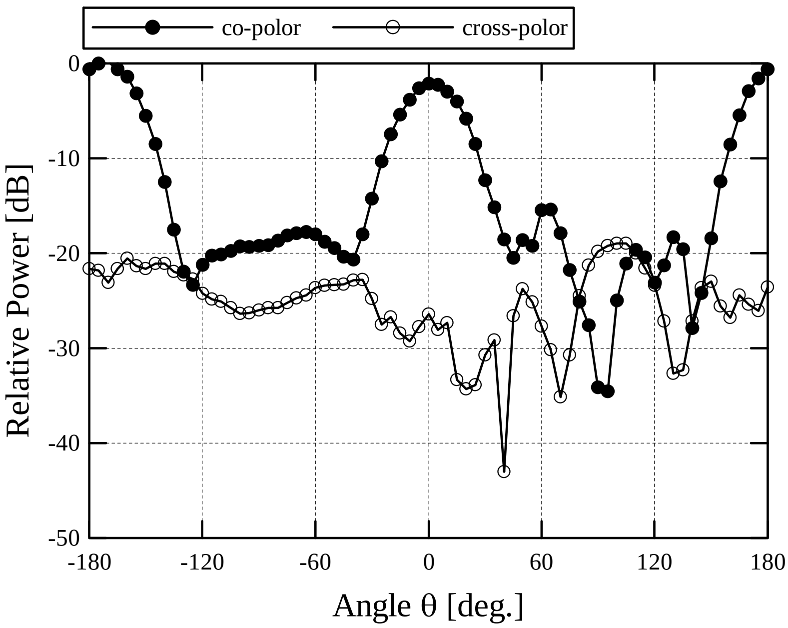


Figure 3.7 Measured return loss and isolation of the array antenna

Figure 3.8 (a) shows the measured radiation pattern of the linear polarization (*y* plane) where the feed port is Port-I. The cross polarized radiation on both the E-plane and H-plane are better than -20 dBi. Figure 3.8 (b) shows the measure radiation pattern of the linear polarization (*x* plane) where the feed port is Port-II. Comparing the radiation pattern of the two orthogonal linear polarizations, almost same polarization performance are obtained.

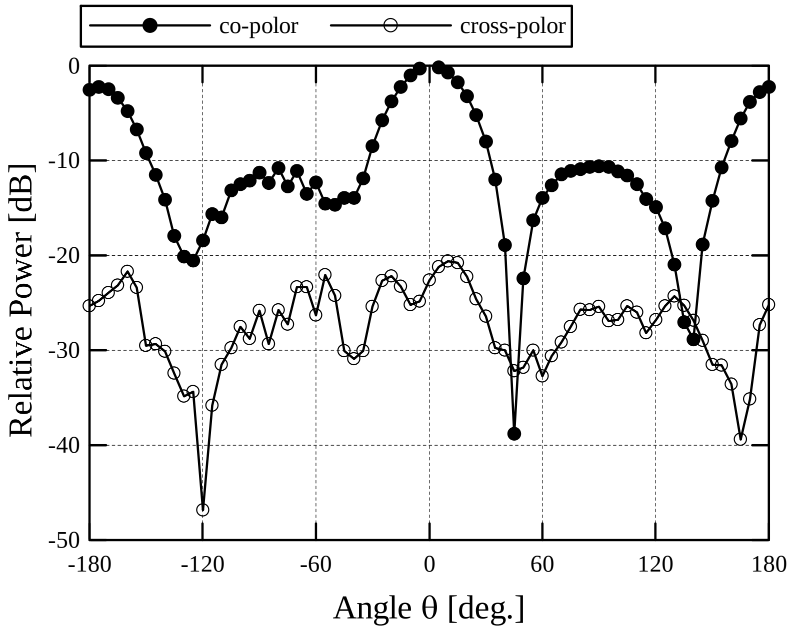


E-plane

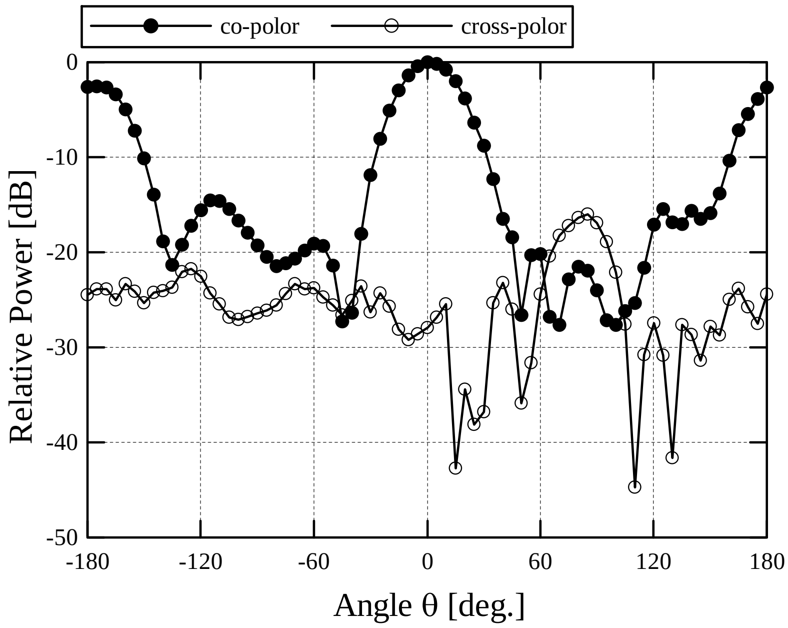


H-plane

(a)



E-plane



H-plane

(b)

Figure 3.8 Measured radiation patterns of array antenna

(a) Excited by Port-I (b) Excited by Port-II

The measured characteristics of the antenna are compared with the simulation date. The measured results agree well with the simulated results.

As a result, the proposed array antenna can be achieved in a wide impedance bandwidth. The good linear polarization performance can be achieved. The broad-band linear polarization ring-slot array antenna for the orthogonal polarization simultaneous use is successfully confirmed in the simulation and the measurement.

3.4 Conclusion

In this chapter, a novel broad-band linear polarization ring-slot array antenna is described. The orthogonal linear polarizations can be realized simultaneously with good polarization performance by using the proposed antenna. Because of the use of the characteristics of the ring-slot antenna and the both-sided MIC technology, the excellent performance such as broad-band, good isolation, and better cross polarization suppression is obtained. In addition, the antenna structure is very simple, and the antenna design is practically easy.

The proposed slot-ring array antenna is designed and achieved. The measured results show that both the S-parameters and polarization performance of the antenna are remarkably excellent. Therefore, the broad-band linear polarization ring-slot array antenna is very suited for the wireless communication systems due to the advantages of a most simple structure and the easier antenna design.

Chapter 4

Circularly Polarized Ring-Sot Array Antenna for Simultaneous Use of the Orthogonal Polarizations

4.1 Introduction

As mentioned in previous chapter, the proposed ring-slot array antenna radiating two orthogonal linear polarizations. However, there are other aspects that are equally important and should be considered in a complete antenna design. These include the design of feed, polarization diversity. In this chapter, the design consideration for circular polarization ring-slot array antenna is presented. Figure 4.1 shows the technical concept for circularly polarized ring-slot array antenna, where a π/2 hybrid circuit is integrated with the antenna. In this approach, the simultaneous use of the right-hand circular polarization (RHCP) and the left-hand circular polarization (LHCP) can be achieved.

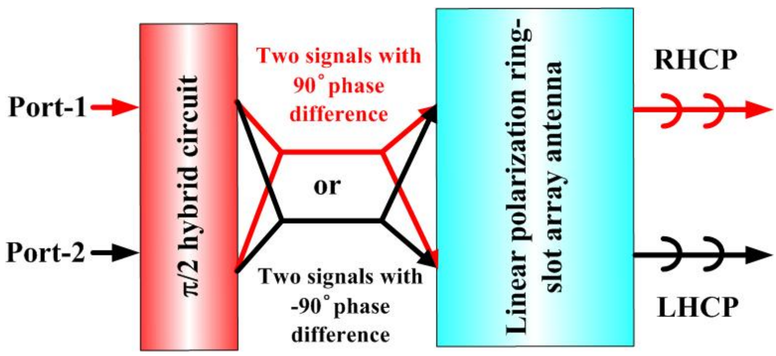


Figure 4.1 Basic configuration of the proposed circularly polarized array antenna

In this chapter, a novel broad-band ring-slot array antenna for simultaneous use of orthogonal polarizations is described. In this antenna, the broad-band performance is obtained by integrating a 2×2 ring-slot array antenna that described in chapter 3, and a broad-band $\pi/2$ hybrid circuit. The simultaneous use of the right-hand circular polarization (RHCP) and the left-hand circular polarization (LHCP) is achieved using orthogonal feed circuits on three layers. The both-sided MIC technology is effectively employed in forming this type of slot array antenna. Experimental results show that the proposed antenna has good circular polarization characteristics for both the LHCP and the RHCP. The measured impedance-bandwidth of return loss better than -10 dB is about 47% both for the LHCP and the RHCP. The 3 dB axial ratio (AR) bandwidths are 25% (RHCP) and 29% (LHCP). The isolation between the two input ports is better than -35 dB at center frequency of 7.5 GHz.

4.2 Circularly Polarized Ring-slot Array Antenna Using $\pi/2$ Hybrid Circuit

Antennas exhibiting circular polarization diversity and broad-band performance have the advantages of frequency reuse for doubling the system capability and a high degree of polarization control to optimize system performance. A number of antenna architectures, offering circular polarization agility, have been proposed [32]-[34]. In these antennas, circular polarization is obtained and the polarization diversity is achieved by using pin-diodes embedded in the antenna. Due to the simple structure, these antennas are attractive for wireless communications, being especially effective for polarization diversity. However, one main disadvantage of these antennas is very narrow bandwidth. Many other antennas are reported to obtain broad-band circular polarization. In [35], a typical circular-ring slot antenna utilizing a strip-line hybrid coupler feed network achieves good broad-band circular polarization performance. In [36], a broad-band annular-slot antenna array with circular polarization has been reported. In these papers, the circular polarization with broad-band performance has been discussed so far. However, there is no report that investigates broad-band antennas with circular polarization diversity.

Therefore, a ring-slot array antenna is designed to radiate two orthogonal circular polarizations (RHCP/LHCP) with broad bandwidth. The structure of the proposed array antenna is shown in Figure 4.2. The 2×2 ring-slot array and a π/2 hybrid circuit are integrated in the proposed antenna. The π/2 hybrid circuit provides two equal input powers with ±90 degrees phase difference for the 2×2 ring-slot antenna array. The 2×2 ring-slot antenna array can provide simultaneous use of the orthogonal circular polarizations with broad bandwidth. The proposed antenna is constructed with 2 layer dielectric substrates, conductive 3 layers and two input port (Port-A and Port-B).

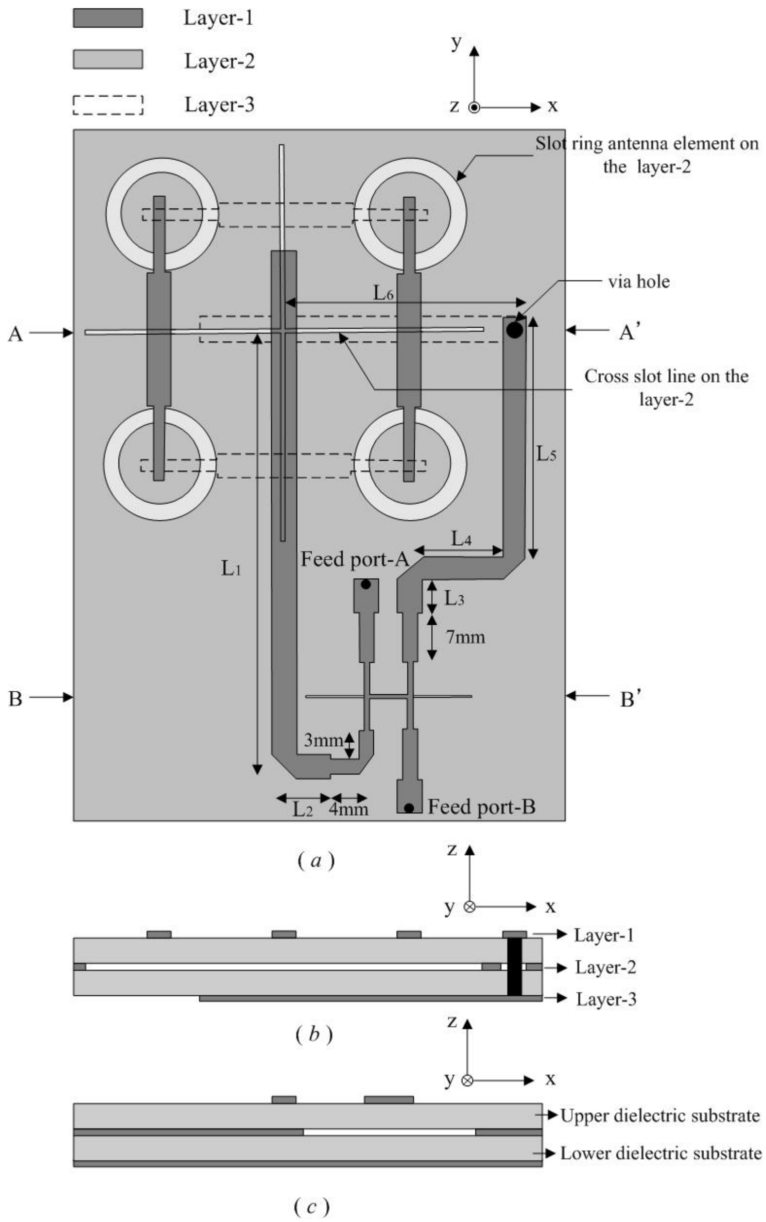


Figure 4.2 Structure of ring-slot array antenna (a) Top view (b) Side view (A-A') (c) Side view (B-B')

In chapter 3, a novel linear polarization ring-slot array antenna with simple structure is described. The array antenna shown in Figure 3.1 can radiate two orthogonal linear polarizations. If two RF signals are fed to the two port of the array antenna respectively with ±90 degrees phase difference, the circular polarization can be realized. In the case of the two RF signals which have +90 deg. phase difference are fed to the two input ports (Port-I and Port-II), the RHCP can be realized. When the phase difference of the two RF signals is -90 deg, the LHCP can be realized. Therefore the proposed slot array antenna can radiate orthogonal circular polarizations simultaneously.

The circular polarization performance of the array antenna is simulated by the HFSS. The simulation model is shown in Figure 3.1. In the simulation, the phase difference between the two RF signals (Port-I *vs.* Port-II) is +90 degrees and -90 degrees to realize the RHCP and the LHCP, respectively. The design frequency is 7.5 GHz.

Figure 4.3 shows the simulated axial ratio (AR) of the 2×2 ring-slot array antenna for both the RHCP and the LHCP. As a result, the axial ratio (AR < 3 dB) relative bandwidth of the RHCP and the LHCP are 51% and 50%, respectively. The broad bandwidth of axial ratio is confirmed mainly due to the orthogonal feed circuits realized by the use of Both-Sided MIC technology.

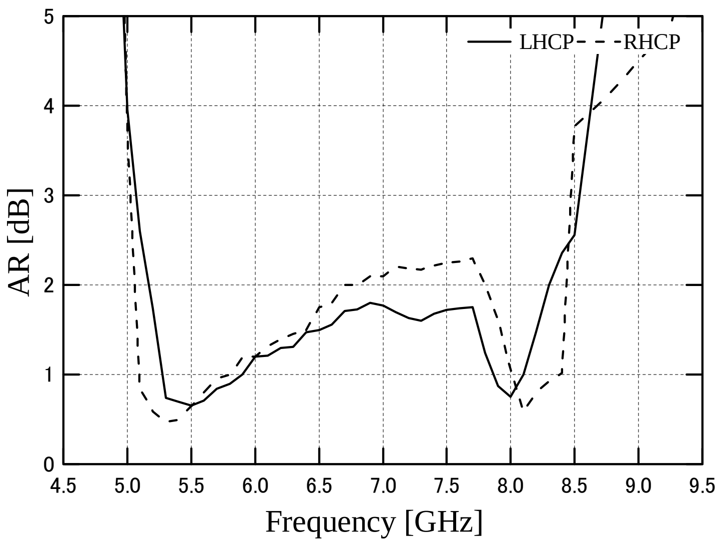
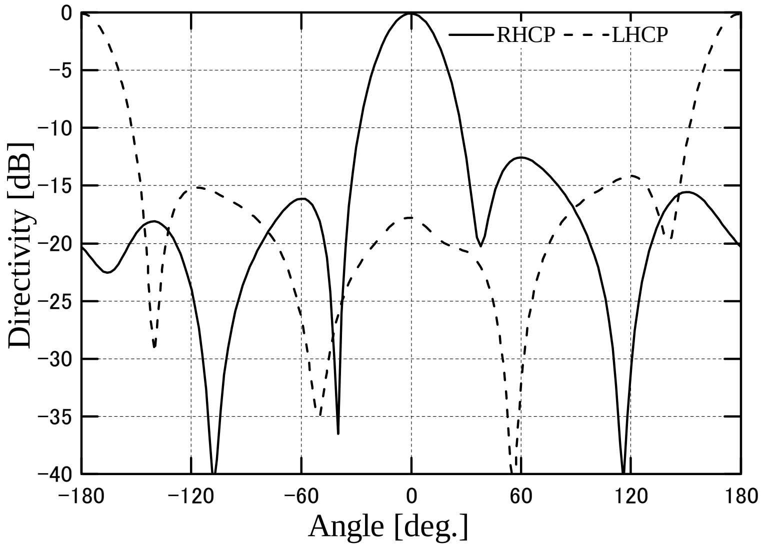
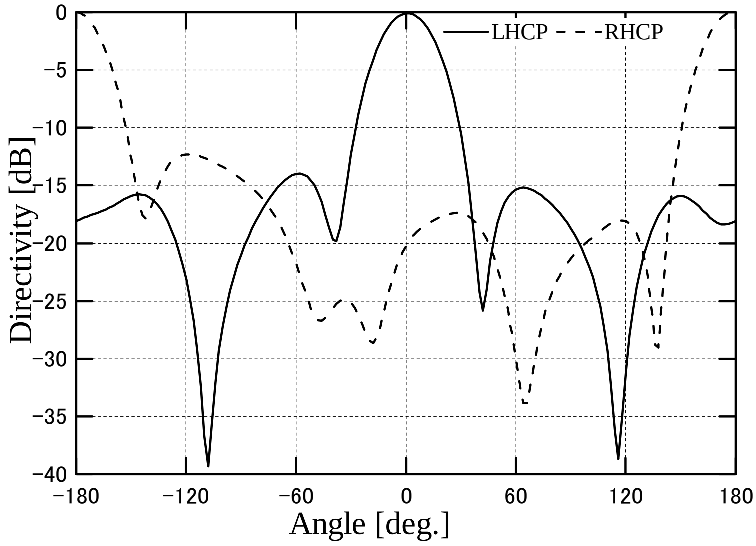


Figure 4.3　Simulated axial ratio (AR) of the array antenna

The far field of the 2×2 ring-slot antenna array is also simulated by HFSS. Figure 4.4 shows the radiation patterns of the proposed ring-slot antenna array. The RHCP and the LHCP can be obtained by two RF signals fed to the two input ports with ±90 degrees phase difference.



(a)



(b)

Figure 4.4 Radiation patterns of the 2×2 ring-slot antenna array (a) RHCP (two input point which have +90 deg. phase difference) (b) LHCP (two input point which have -90 deg. phase difference). Frequency: 7.5GHz

According to these results and the S-parameters of the array antenna mentioned in section 3.2, the broadband circular polarization slot antenna array for orthogonal polarization simultaneous use is theoretically confirmed.

4.3 Broad-Band Microstrip π/2 Hybrid Circuit

A broad-band π/2 hybrid circuit shown in Figure 4.5 is used in the proposed antenna. This Double-Sided MIC π/2 hybrid circuit was originally proposed by de Ronde [37]. This type of coupler has two advantages over the conventional branch-line coupler: smaller size and much wider bandwidth [38]. The input signal from the feed Port-1 is divided to Port-2 and Port-4 with +90 degrees phase difference. The Port-3 is an isolated port. When the feeding port is Port-3, the output ports are Port-2 and Port-4, and the Port-1 is isolation port. In this case, the phase difference between Port-2 and Port-4 is -90 degrees.

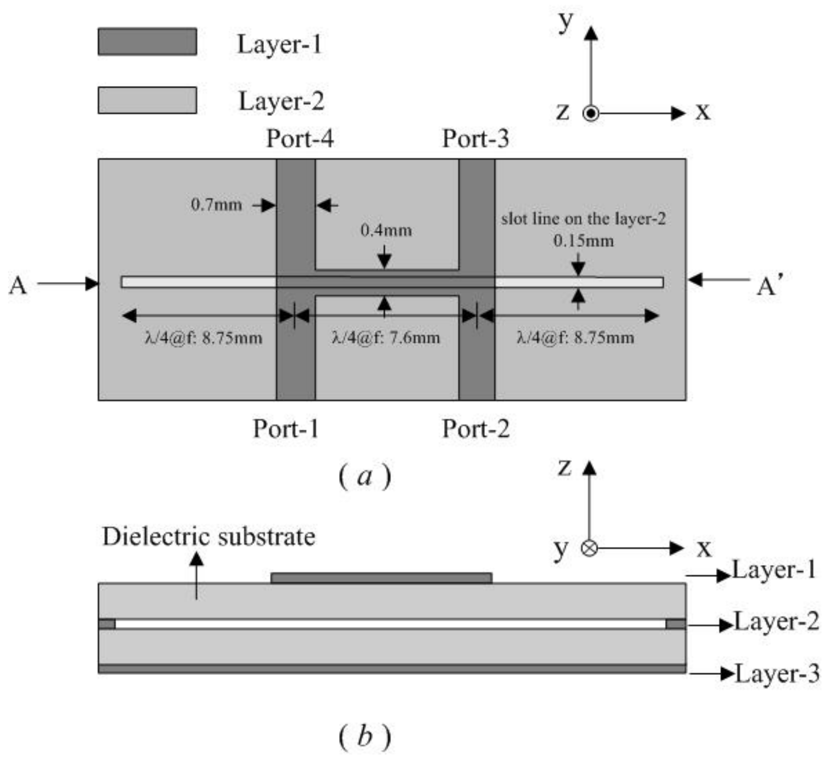


Figure 4.5 Structure of the microstrip π/2 hybrid circuit
(a) Top view (b) Side view (A-A')

Figure 4.6 shows the simulated S-parameters of the π/2 hybrid circuit. In this case, the RF signal is fed to Port-I. The insertion loss is less than 1 dB in the frequency range of 6 GHz to 9 GHz. The isolation and the return loss are better than -20 dB in the same band. Figure 4.7 shows the frequency characteristics of the phase. The phase difference of +90 deg. is obtained in the frequency range of 6 GHz to 9 GHz.

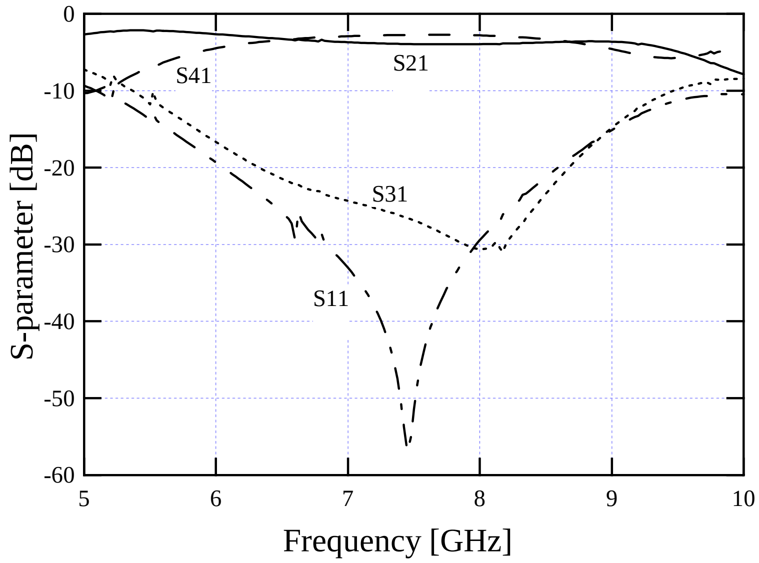


Figure 4.6 Simulated S-parameter of the circuit

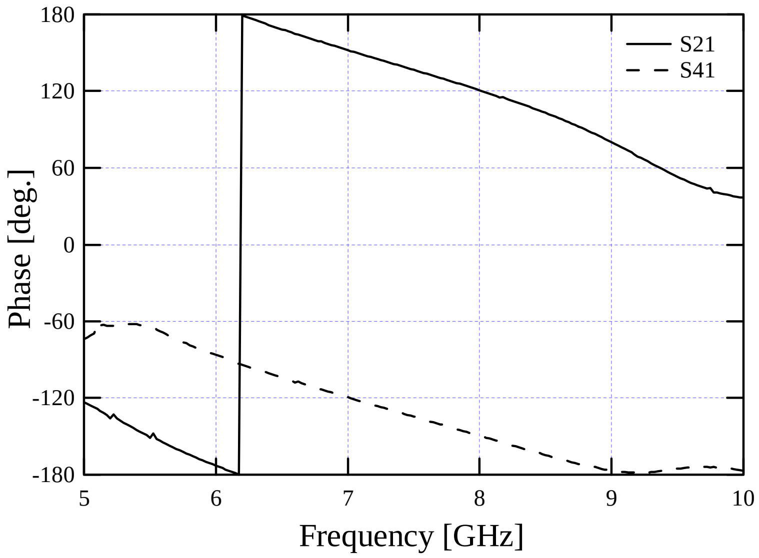
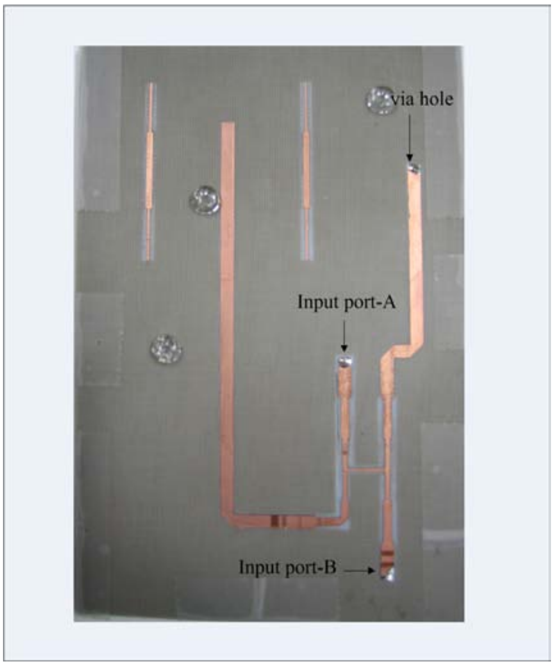


Figure 4.7 Simulated phase difference of the circuit

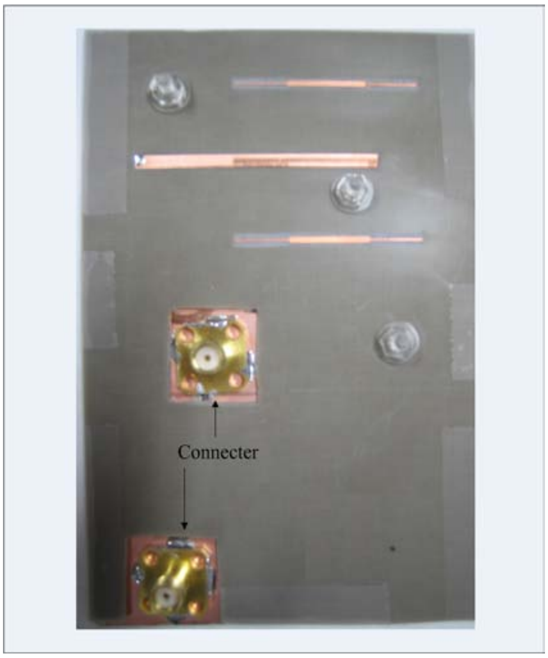
As a result, the broad band performance and $\pi/2$ phase shift behavior can be achieved in this circuit.

4.4 Experiment

According to the better performance described above, the broad-band circular polarization ring-slot array antenna is fabricated on a Teflon Glass Fiber substrate with the relative dielectric constant ε_r of 2.15. The thickness of the substrate is 0.8 mm. The fabricated ring-slot array antenna for the experiment is shown in Figure 4.8. The size of the antenna ground plane is 75mm×110mm. The $\pi/2$ hybrid circuit and the ring-slot array are integrated on three layer substrates. The electric length of two feed circuits are the same to provide the excitation of antenna orthogonally, where $L1+L2=L3+L4+L5+L6 = 2.8\ \lambda_g$ as shown in Figure 4.1. By feeding the RF signals to the input ports of proposed antenna (Port-A and Point-B), the RHCP and LHCP can be obtained simultaneously.



(a)



(b)

Figure 4.8 Photos of the proposed ring-slot array antenna
(a) Top view (b) Bottom View

The performance is measured through the experiment using an Agilent Network Analyzer 8510C in an anechoic chamber. A linear polarization horn antenna is used to measure the proposed antenna. The horn antenna is set at a distance of 2m from the proposed antenna. The proposed antenna is located on a turn table.

Figure 4.9 shows the measured return loss of the proposed ring-slot array antenna. The return loss impedance bandwidth of better than -10 dB is about 47% (5.37 GHz - 8.76 GHz). The measured -10 dB return loss bandwidth of the array antenna including the $\pi/2$ hybrid is better than the simulated -10 dB return loss bandwidth of the only antenna array as shown in Figure 3.3. The reason is that, the broad band $\pi/2$ hybrid circuit can improve the return loss performance of the proposed antenna. And from the result shown in Figure 4.10, a good isolation performance better than -30dB is obtained in the frequency range of 6.3GHz to 8GHz.

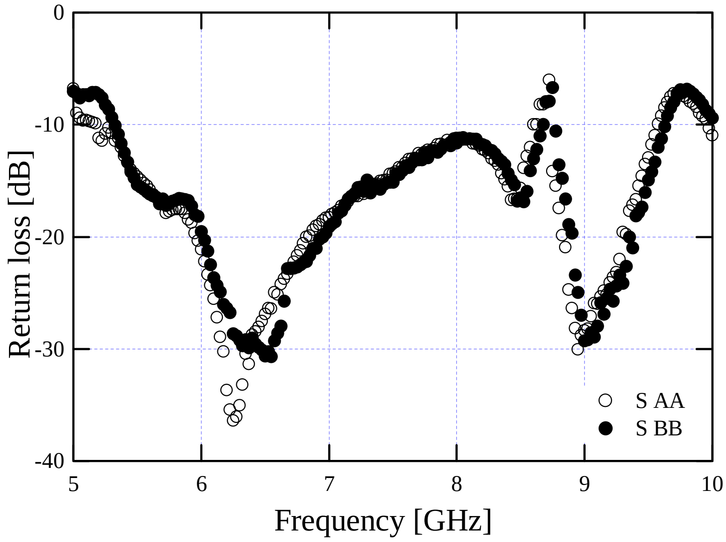


Figure 4.9   Measured return loss of the proposed array antenna

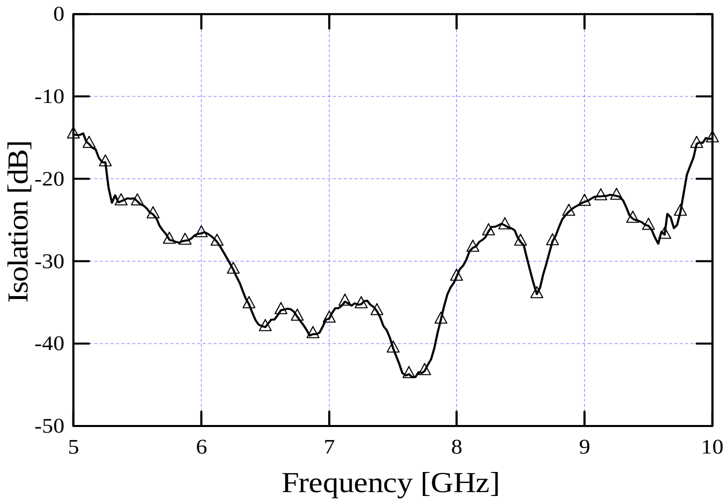


Figure 4.10   Measure isolation of the two proposed array antenna input ports

Figure 4.11 shows the measured axial ratio (AR). The 3 dB axial ratio bandwidth for the RHCP and the LHCP are 25% and 29% with respect to 7.25 GHz, respectively. In the experiment, the 90 degrees phase difference and the amplitude of the two linear polarization components is changed with the frequency changing due to the frequency characteristics of the $\pi/2$ hybrid circuit. In the simulation, the 90 degrees phase difference and the same amplitude of two linear polarization components are set up in whole frequency band. Therefore, the measured axial ratio bandwidth is narrower than the simulated result as shown in Figure 4.3.

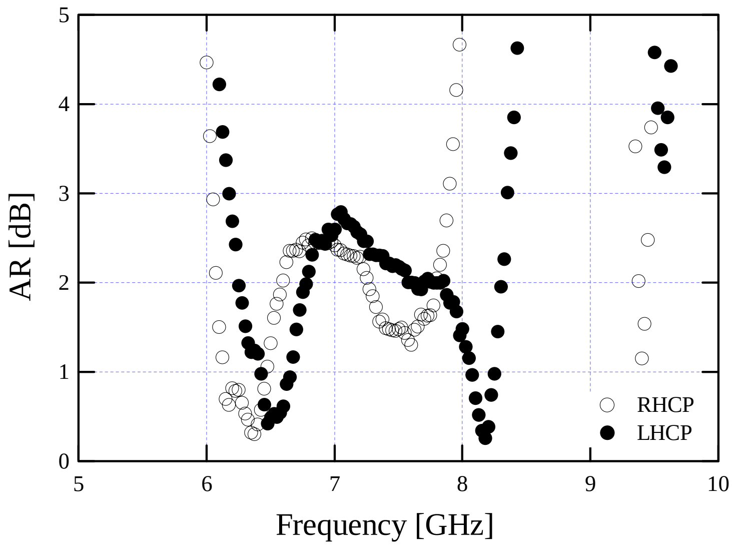


Figure 4.11 Measured axial ratio (AR) of the proposed array antenna

Figure 4.12 shows the orthogonal linear polarization components where the feed port is Port-A (RHCP is radiated to 0 degree direction). The horizontal plane of the horn antenna is *xz*-plane, and the vertical plane of the horn antenna is *yz*-plane. Both the horizontal (*xz* plane) and the vertical (*yz* plane) linear polarization components are presented, and the two components are almost same. Figure 4.13 shows the orthogonal linear polarization components where the feed port is Port-B (LHCP is radiated to 0 degree direction). The two components are also almost same. Therefore, the RHCP and the LHCP are confirmed, because the 90 deg. phase difference is obtained using the $\pi/2$ hybrid circuit.

As a result, the broad-band circularly polarized ring-slot antenna for simultaneous use of the orthogonal polarizations has been experimentally confirmed. Due to the exact calculation of electric length in the feed circuits, the good circular polarization performance can be achieved. The simulated gains both of the RHCP and LHCP are 9.7 dBi at 6.4 GHz. In addition, the isolation of the two input ports is better than -30 dB in a wide bandwidth. The broad-band circularly polarized ring-slot array antenna for the orthogonal polarization simultaneous use is realized for the first time as far as the authors know.

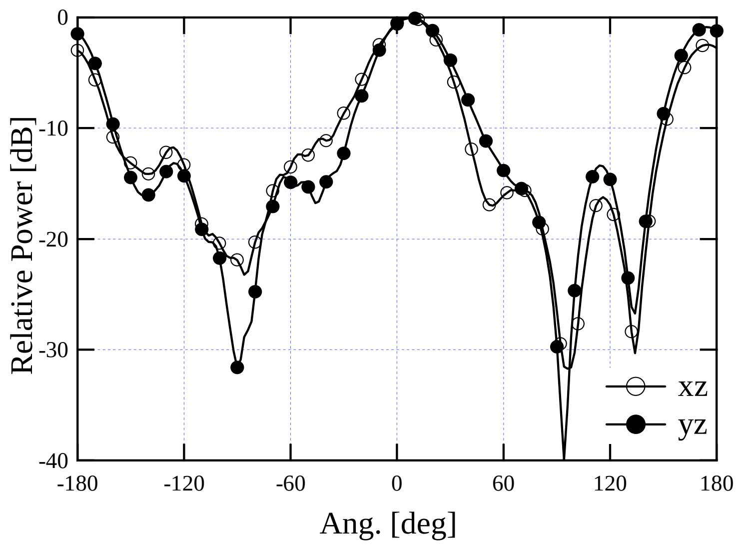


Figure 4.12 Radiation pattern of the proposed array antenna (Port-A)
Frequency : 6.4 GHz

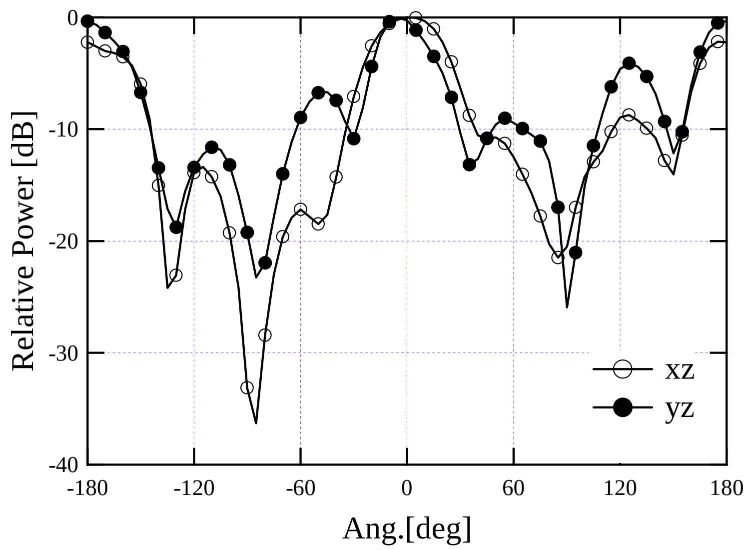


Figure 4.13 Radiation pattern of the proposed array antenna (Port-B)
Frequency : 6.4 GHz

4.5 Conclusion

In this chapter, a broad-band circular polarization annular ring-slot array antenna for simultaneous use of the orthogonal polarizations is proposed. The proposed antenna can provide wide impedance bandwidth of 47%. The 3 dB axial ratio bandwidths are wider than 25% (RHCP) and 29% (LHCP). The Both-Sided MIC technology is effectively applied to configure the proposed slot array antenna.

Excellent performance such as broad-band, good isolation and simultaneous use of the orthogonal circular polarizations is obtained. The proposed ring-slot array antenna can find promising application such as radar and polarimetric sensors. Moreover, by integrating a switch circuit in the proposed antenna, an orthogonal circular polarizations switchable slot array antenna can be realized easily.

Chapter 5

Linear Polarization Switchable Ring-Slot Array Antenna Using SPDT Circuit

5.1 Introduction

A broad-band ring-slot array antenna which can radiate linear polarizations and the circular polarizations is described in last two chapters. However, the polarization switching function can not be obtained by using the array antennas that mentioned in last two chapters. Various antenna architectures, offering polarization agility, that is, realizing polarization switching function, have been proposed [39] – [41]. In these antennas, polarization diversity is achieved by using PIN diodes or varactor diodes embedded in the antennas. In [39], the polarization angle is controlled by switching the resonant mode of the patch antenna, where the switching of resonant modes is achieved by adjustment of the conditions of the PIN diodes. These antennas are attractive for wireless communications, being especially effective for polarization diversity due to their simple structures. Moreover, a ring-slot antenna that allows polarization diversity has been reported [42]. The characteristics of a single element antenna with polarization diversity have been discussed in these papers; however, the investigation of the array antenna with polarization diversity has not been involved. Recently, a slot-ring array antenna with polarization switchable function is proposed in a paper [43], where a four elements ring-slot array antenna was presented whose orthogonal polarization can be switched. The orthogonal polarization is switched by using sixteen switching diodes embedded in the slot-ring antenna elements. However, this array antenna requires many diodes for antenna fabrication.

Therefore, by using a Single Pole Double Throw (SPDT) switch circuit, a novel linear polarization ring-slot array antenna is proposed and described in this chapter. The linear polarization switchable function is achieved using the SPDT switch circuit. Two Schottky barrier diodes are mounted on a slot ring of the SPDT switch circuit. As the orthogonal linear polarization switching depends on the diode ON/OFF conditions, the polarization angle is easily controlled by the polarity of the bias voltage. The excellent design flexibility of the Both-Sided MIC technology is effectively employed in forming this type of antenna. Experimental results show that the proposed antenna has good polarization characteristics for the two orthogonal linear polarizations. The radiation performances of two orthogonal polarizations are almost the same. Consequently, a linear polarization switchable ring-slot array antenna is successfully verified.

5.2 Design of Ring-Slot Array Antenna For Linear Polarization Switching

A linear polarization switchable ring-slot array antenna is mentioned in section 5.1; the antenna design is performed on the HFSS and ADS as well.

5.2.1 Antenna Configuration

The proposed linear polarization switchable ring-slot array antenna is shown in Figure 5.1. The antenna consists of the ring-slot array antenna that mentioned in chapter 3 and the SPDT switch circuit. The ring-slot array can radiate two orthogonal linear polarizations. The SPDT circuit switches two feed circuits of RF signal to the ring-slot array antenna. The array antenna is constructed with 2 layer dielectric substrates and 3 conductive layers.

The configuration and basic operation of the ring-slot array is explained chapter 3. A better impedance performance and linear polarization performance is obtained by the proposed ring-slot array. By fed a RF signal to Port-I or Port-II (Figure 3.1), the two orthogonal linear polarizations can be realized easily.

The linear polarization switchable array antenna that described in this chapter can have the polarization switching function due to the using of a novel three layers SPDT switch circuit. And the basic operation and the configuration of the SPDT switch circuit will be described in detail in the next section.

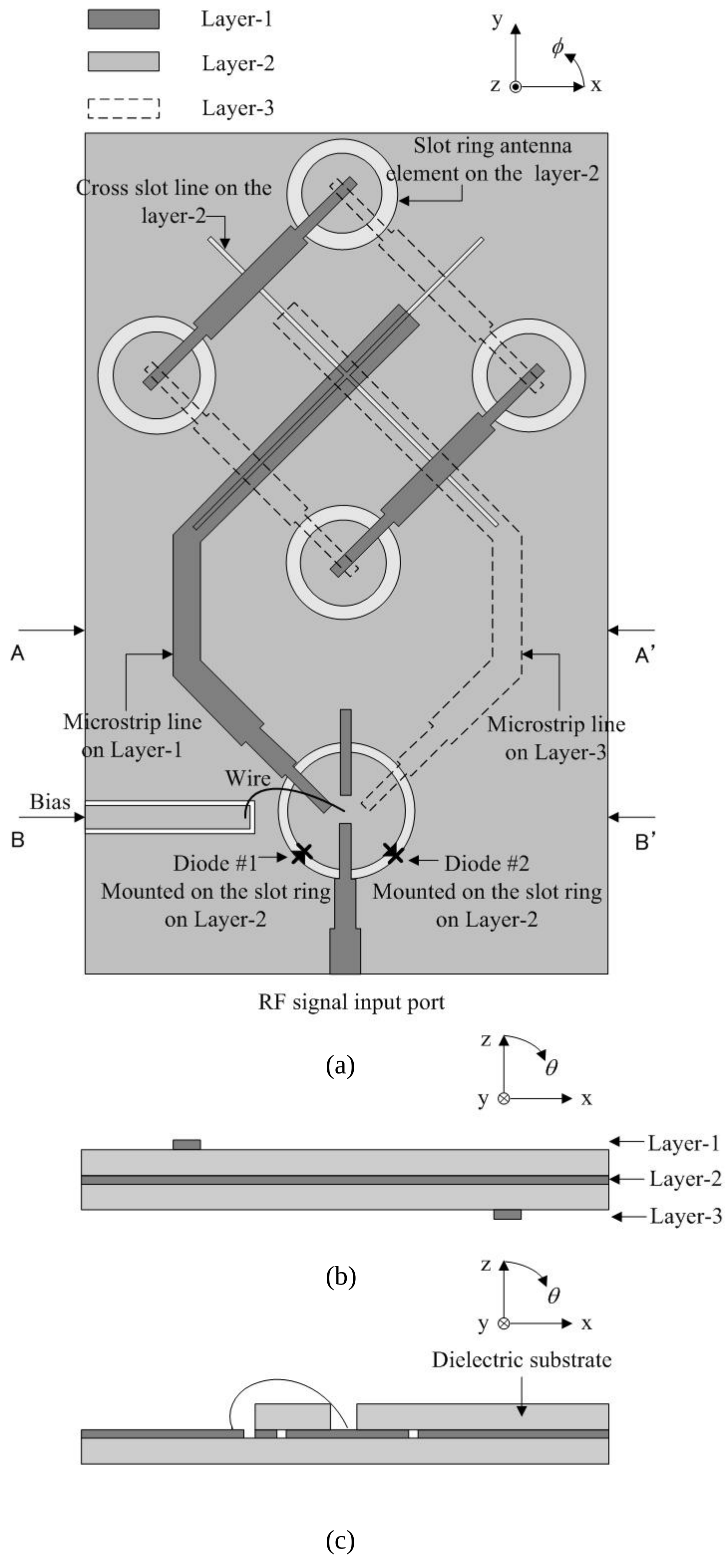


Figure 5.1 Linear polarization switchable ring-slot array antenna

(a): Top view (b): Side view A-A' (c): Side view B-B'

5.2.2 SPDT Switch Circuit

Figure 5.2 shows the configuration of the proposed SPDT switch circuit. The SPDT circuit consists of a two wavelength ring-slot on layer-2, an input microstrip line and output microstrip lines connected to Port-2 on layer-1 and Port-3 on layer-3, and two Schottky barrier diodes mounted on the ring-slot. The switching bias is supplied to the switching diodes through the conductor wire connected to the coplanar waveguide. Two 1/2 wavelength open stub microstrip lines on layer-1 and layer-3 are used in the switch circuit to isolate the two output ports. As shown in Figure 5.2, two Schottky barrier diodes are loaded on the ring-slot at ±45 degrees with respect to the input microstrip line (Port-1).

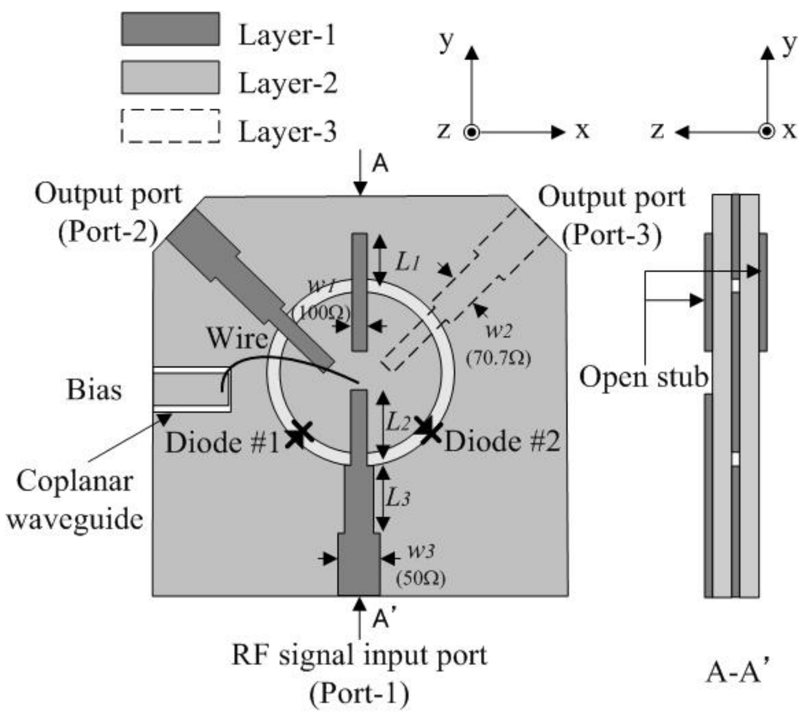
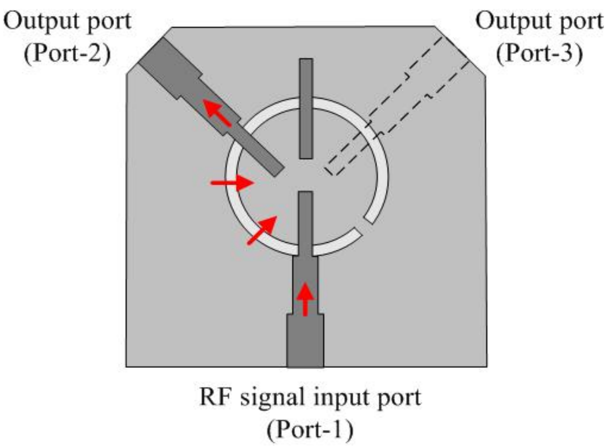
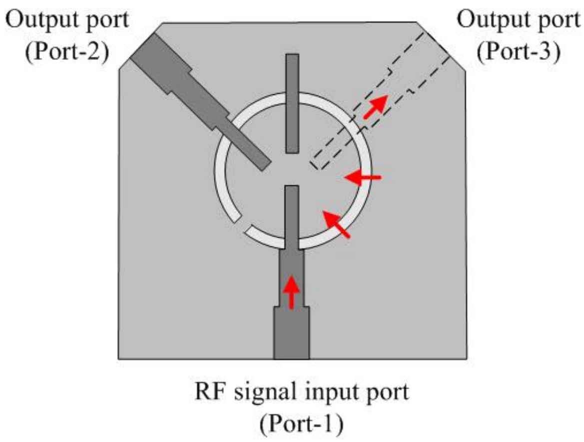


Figure 5.2 Configuration of the SPDT switch circuit
(a): Top view (b): Side view A-A'

The basic behavior of the proposed SPDT switch circuit is shown in Figure 5.3. In this type of three layers SPDT switch circuit, the RF signal propagates along each slot line according to the polarity of the switching bias voltage. When a positive voltage is applied to the inner conductor of ring-slot, the diode #2 is ON, and the diode #1 is OFF. In this condition, the switch circuit transmits the RF signal to the Port-2 on layer-1 as shown in Figure 5.3 (*a*). When the polarity of the bias voltage applied to the diode is reversed, the switch circuit transmits the RF signal to the Port-3 on layer-3 as shown in Figure 5.3 (*b*). Therefore, the output port of RF signal can be switched easily.



(a)



(b)

Figure 5.3 Schematic electric field of the SPDT switch circuit
(a): Diode #1 OFF, Diode #2 ON (b): Diode #1 ON, Diode #2 OFF

The characteristics of the SPDT switch circuit are designed and fabricated. The circuit is fabricated on a Teflon Glass Fiber substrate with the relative dielectric constant ε_r of 2.15. The thickness of the substrate is 0.8 mm. The optimized parameters of the SPDT switch circuit dimensions are as follows: $L_1 = L_2 = 0.25\lambda g = 7.6$ mm, $L_3 = 0.25\lambda g = 7.46$ mm, $w_1 = 0.7$ mm, $w_2 = 1.4$ mm, $w_3 = 2.4$ mm; the characteristic impedance of the feed microstrip lines (Port-1, 2 and 3) is 50 Ω. The characteristic impedance of microstrip lines connected to the ring-slot is 70.7 Ω for the impedance matching. The length of the conductor wire is 1.5 cm. The length and width of the ring-slot are 68.44 mm and 0.2 mm, respectively. Two Schottky barrier diodes (Metelics MSS30, 154-B10B) are used in the SPDT switch circuit.

The measured return loss is shown in Figure 5.4. The -10 dB return loss bandwidth is 1.45 GHz from 6 GHz to 7.45 GHz and 1.38 GHz from 8.4 GHz to 9.78 GHz for both the positive and the negative bias. Simulated result is also shown in the same figure.

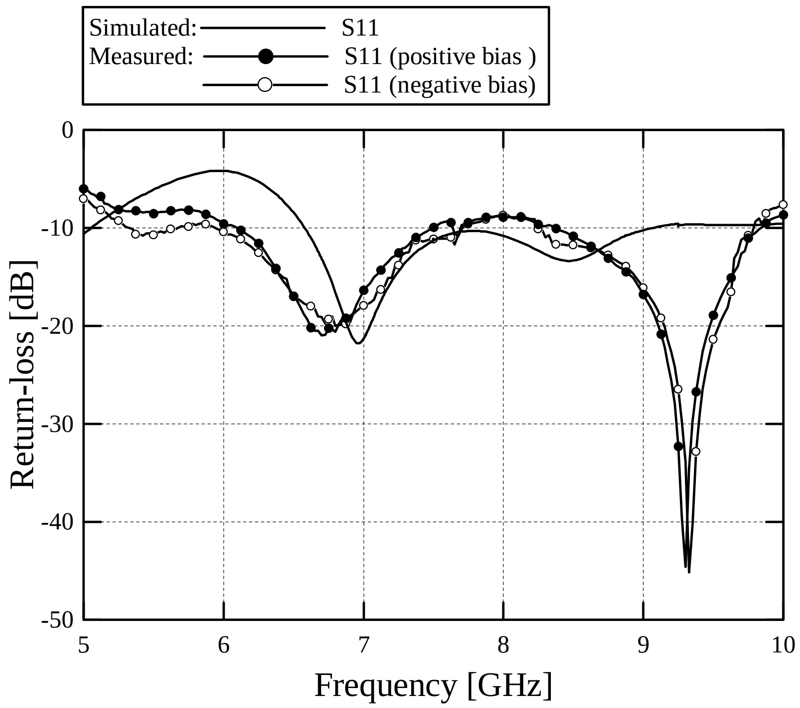


Figure 5.4 Return loss of the SPDT switch circuit

When a positive voltage is applied to the SPDT switch circuit, the diode #2 is ON, and the diode #1 is OFF. The simulated S-parameters are shown in Figure 5.5. The isolation performance S31 is better than -20 dB in the frequency range of 6.5 GHz to 8.6 GHz. A better insertion loss S21 is obtained in the same band. Figure 5.6 shows the measured results. The isolation performance S31 is better than -20 dB in the frequency range of 6.5 GHz to 7.65 GHz. The insertion loss S21 is less than -3 dB in the same band. In the opposite polarity of the bias voltage, the same result is obtained. Comparing the experimental date with the simulation date, the discrepancy can be found which is mainly due to the effect of the diode characteristics. In the simulation, the ON state diode is replaced by a conductor line.

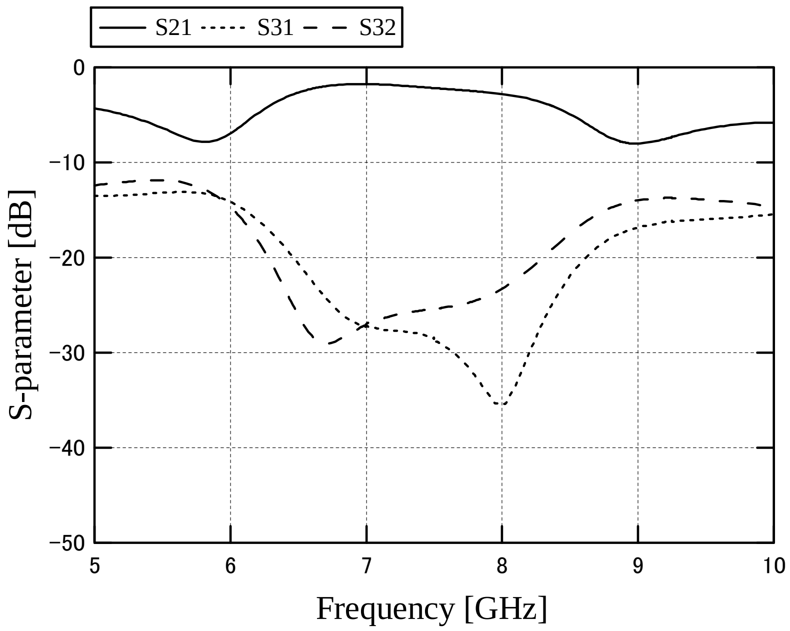


Figure 5.5　Simulated S-parameters of the SPDT switch circuit
(Diode #1: OFF, Diode #2: ON)

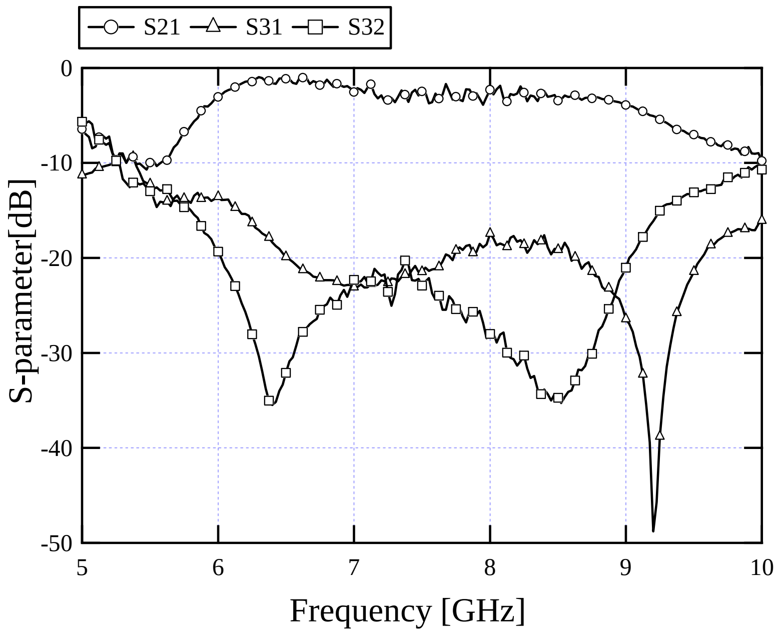


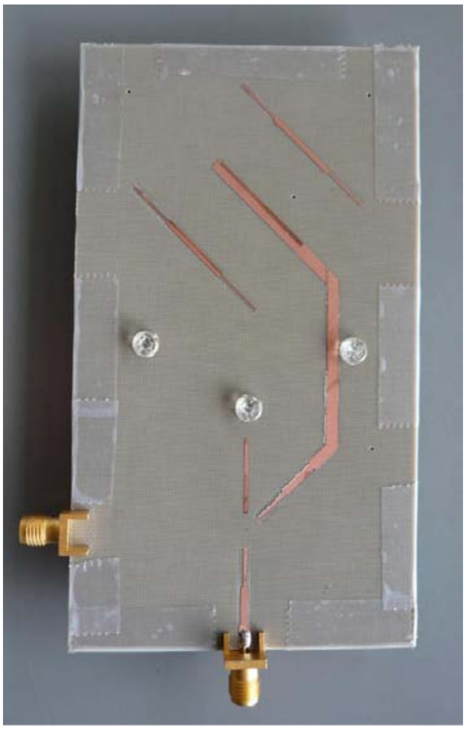
Figure 5.6　Measured S-parameters of the SPDT switch circuit
(Diode #1: OFF, Diode #2: ON)

According to these results, a wide band SPDT switch circuit is achieved. The better circuit performance can be realized by matching the impedances of microstrip lines and ring-slot on the SPDT switch circuit further more.

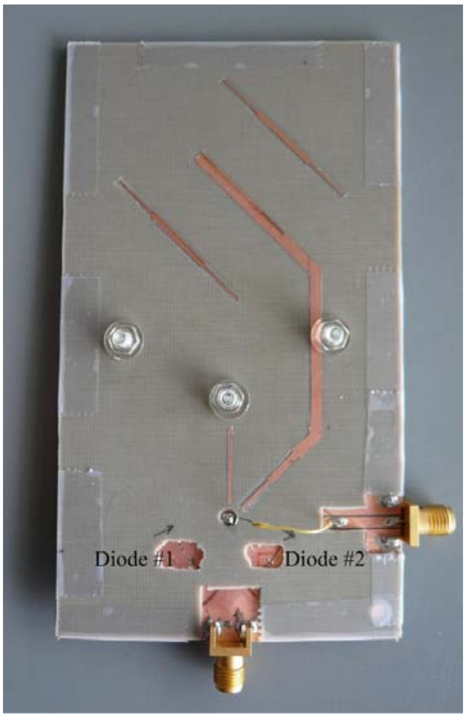
As a result, the basic behavior of the SPDT switch circuit is confirmed theoretically and experimentally. Moreover, the orthogonal linear polarization switchable ring-slot array antenna integrating the 4 elements ring-slot array and the SPDT switch circuit can be simply achieved in the same substrate.

5.3 Experimental Results and Discussion

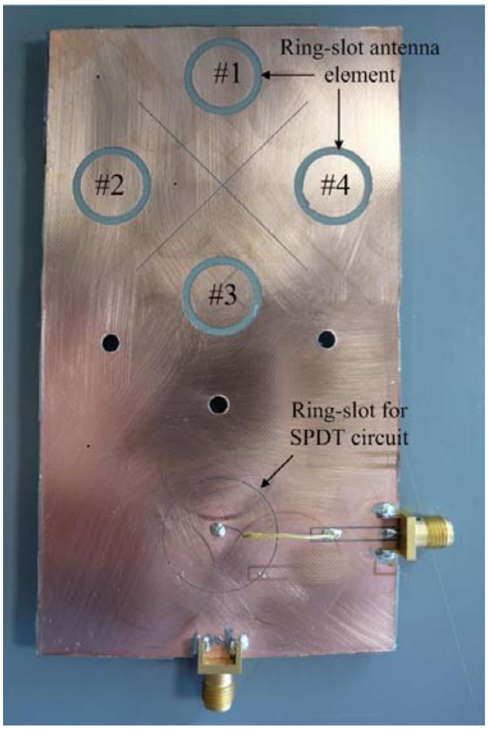
The integrated orthogonal linear polarization switchable array antenna of the ring-slot array and the SPDT switch circuit is fabricated and measured. The photos of the fabricated antenna are shown in Figure 5.7. The size of the ground plane is 70 mm × 120 mm.



(a)



(b)



(c)

Figure 5.7 Photos circuit of the SPDT switch

(a): Top-view (Layer-1) (b): Bottom view (Layer-3) (c): Ring-slot array (Layer-2)

Figure 5.8 shows the measured return loss of the array antenna. The return loss better than -10 dB is obtained in a frequency range of 6.3 GHz to 7.8 GHz for both the positive bias and the negative bias.

The far fields of the array antenna are measured using a linear polarization horn antenna. The horn antenna is set at a distance of 2 m from the array antenna. The array antenna is located on a turn table. Radiation patterns of the proposed ring-slot array antenna are shown in Figure 5.9 and Figure 5.10. The measure frequency is 7 GHz. When the positive voltage is applied to the array antenna, the diode #2 is ON and the diodes #1 is OFF. The main polarization angle ϕ of the antenna is tilted to be +45 degree. The radiation patterns are shown in Figure 5.9. When the polarity of the bias voltage is reversed, diode #1 is ON and the diode #2 is OFF. The main polarization angle ϕ of the antenna is turned to be -45 degree as shown in Figure 5.10.

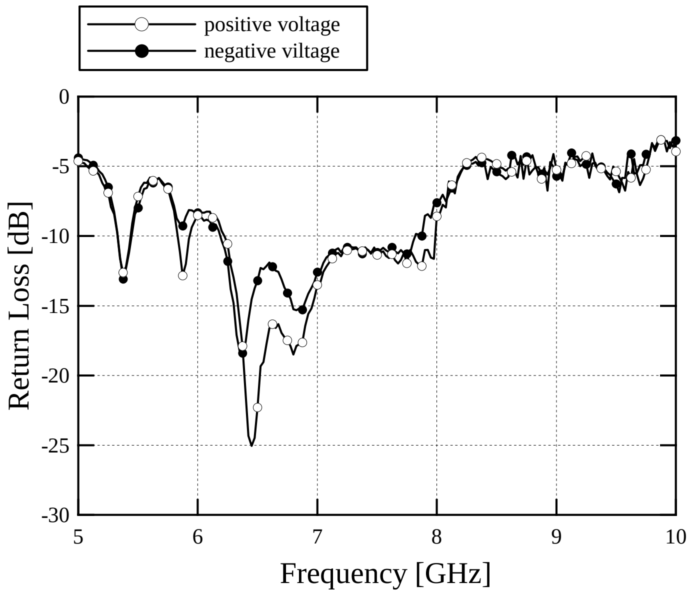
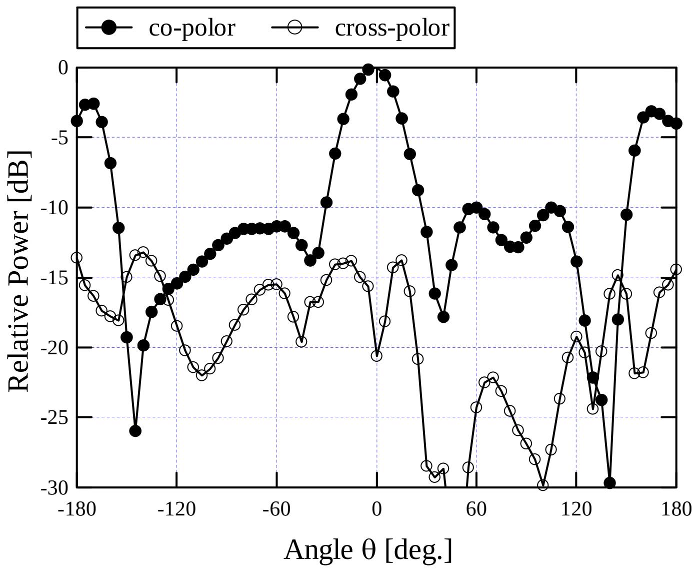
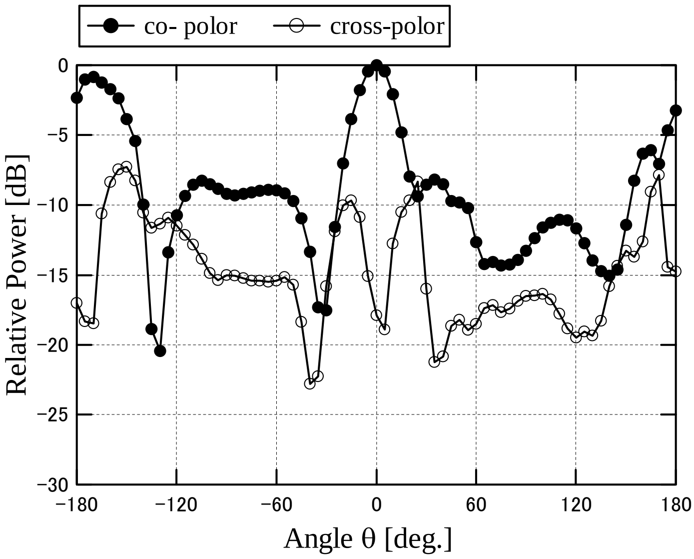


Figure 5.8　Measured return loss of the array antenna

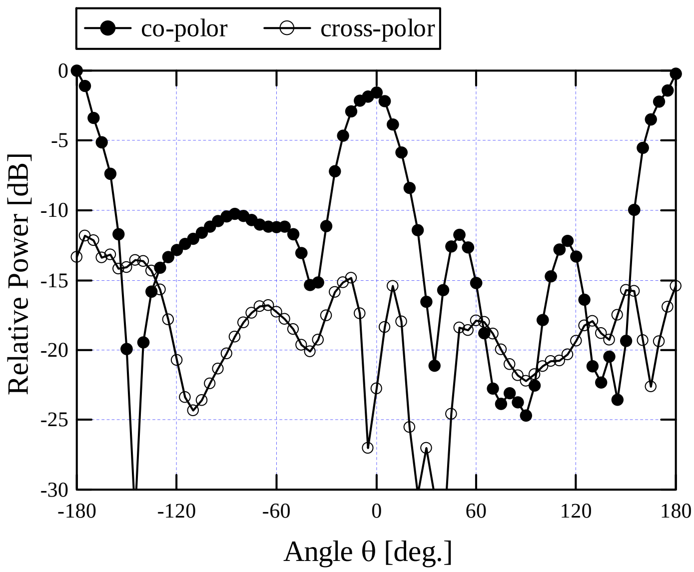


E-plane

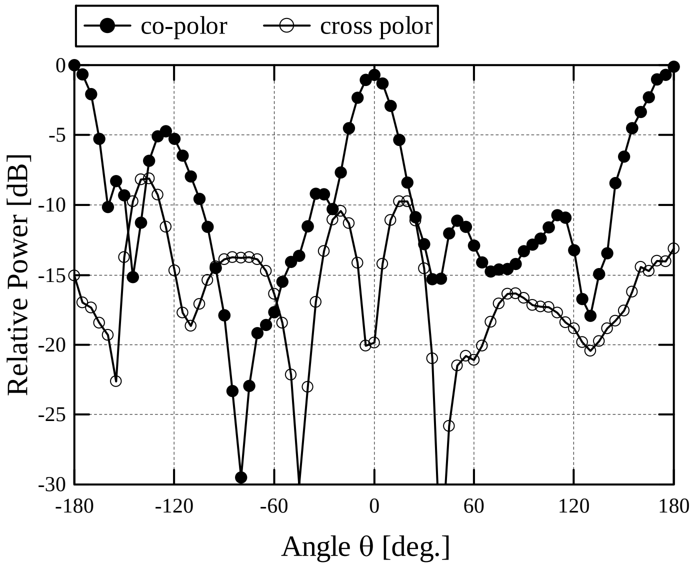


H-plane

Figure 5.9 Measured radiation pattern of the polarization switchable array antenna at 7 GHz, $\phi = +45$ degree, Diode #2 is ON



E-plane



H-plane

Figure 5.10 Measured radiation pattern of the polarization switchable array antenna at 7 GHz, $\phi = -45$ degree, Diode #1 is ON

The radiation patterns of the two orthogonal linear polarizations are almost same. In an addition, the cross polarization level is about -20 dB at the bore-sight for both ϕ = +45 degree linear polarization and ϕ = -45 degree linear polarization. The better cross polarization suppression of the array antenna is obtained because of the complementarity effect of the mirror symmetry antenna structure and the good isolation performance of the SPDT switch circuit.

The good performance of the two orthogonal linear polarizations is achieved, and the polarization switching function is also realized by using the array antenna. Consequently, the orthogonal linear polarization switchable ring-slot array antenna is experimentally verified.

5.3 Conclusion

In this chapter, a novel linear polarization switchable ring-slot array antenna is described, and the characteristics of the antenna are experimentally discussed. The antenna can provide the switching function between the polarization angle of ϕ = +45 degree and ϕ = -45 degree. The Both-Sided MIC technology is effectively applied to form the array antenna. By the use of combination effect of a microstrip-slot parallel power divider and a slot-microstrip series power divider, very simple circuit configuration and good polarization performance can be achieved. The -10 dB return loss bandwidth is obtained over 6.3 GHz to 7.8 GHz frequency range.

Extending this array antenna structure, sixteen elements array or thirty-two elements ring-slot array antenna with linear polarization switching function can be easily realized as well. The proposed slot array antenna can find promising applications such as various radars and polarmetric sensors. Moreover, much wider applications can be found if a reflector is added for a directional radiation pattern. Therefore, the proposed array antenna is practically attractive for advanced wireless communication systems and the other applications.

Chapter 6

Circular Polarization Switchable Ring-Slot Array with Broad-Band

6.1 Introduction

As mentioned above, there are two kinds of polarizations. A linear polarization switchable ring-slot array antenna was described in last chapter. In this chapter, a novel design approach is offered to attain circular polarization switchable ring-slot array antenna fed by an integrated circuit of the 90 degrees branch line hybrid circuit and the SPDT switch circuit. The basic configuration of the circularly polarized switchable array antenna is shown in Figure 6.1. The proposed integrating feed circuit can feed two

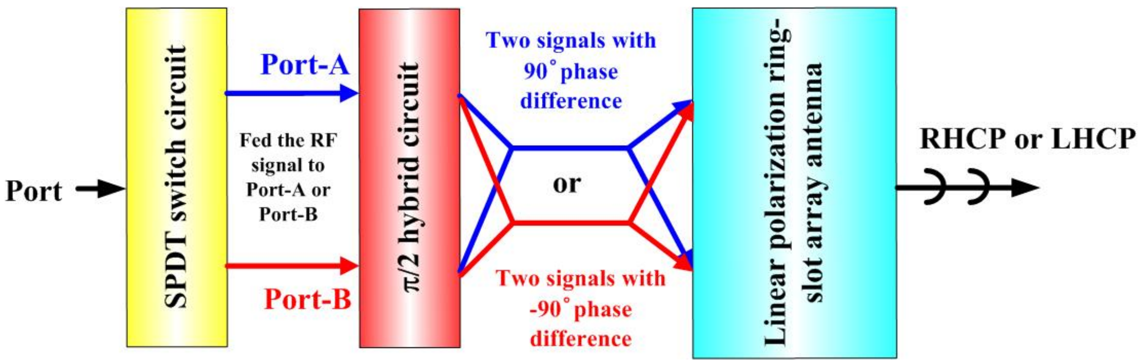


Figure 6.1 Basic configuration of the circular polarization switchable array antenna

RF signals with ±90 degrees and same amplitude to the ring-slot array. Moreover, the 90 degrees phase difference and the -90 degrees phase difference of the two feed RF signals can be switched by the feed circuit. The excellent circular polarization characteristics can be obtained by the ring-slot array. Therefore, a circular polarization switchable ring-slot array antenna can be realized by integrating the ring-slot array, 90 degrees branch line hybrid circuit and SPDT switch circuit, and the proposed array antenna is described in this chapter.

6.2 Principle of Proposed Ring-Slot Array Antenna

A circular polarization switchable ring-slot array antenna is mentioned in section 6.1. The antenna principle is described in this chapter, and the antenna design is performed on the HFSS and ADS as well.

6.2.1 Antenna design

The structure of the circular polarization switchable ring-slot array antenna is shown in Figure 6.2. The antenna consist a ring-slot array, a 90 degrees branch line hybrid circuit and a SPDT switch circuit. The array antenna is constructed with 2 layer dielectric substrates and 3 conductive layers. The ring-slot array that mentioned in chapter 3 is utilized to form this proposed antenna. The impedance performance and circular polarization characteristics of the ring-slot array are described in chapter 3 and section 2, chapter 4. The utilized ring-slot array can radiate the circular polarization with good polarization performance in a wide frequency bandwidth. A conventional 90 degrees branch line hybrid circuit is used in the proposed array antenna. This branch line hybrid circuit can provide the ring-slot array two RF signals with ±90 degrees phases difference and same amplitude. The polarization switchable function can be obtained by the use of a SPDT switch circuit.

A three layers SPDT switch circuit was described in section 5.2.2. This type of SPDT switch circuit can switch the RF signals with excellent circuit performance in a wide frequency bandwidth. In this chapter, in order to integrate the SPDT switch circuit and branch line hybrid circuit in same structure, the design of the SPDT switch circuit has a minor change. The used SPDT switch circuit in this chapter is constructed with 1 layer dielectric substrates with 2 conductive layers. The changed SPDT switch circuit is remarkable suited for composing the proposed circular polarization switchable ring-slot array antenna, and is described in next section in detail.

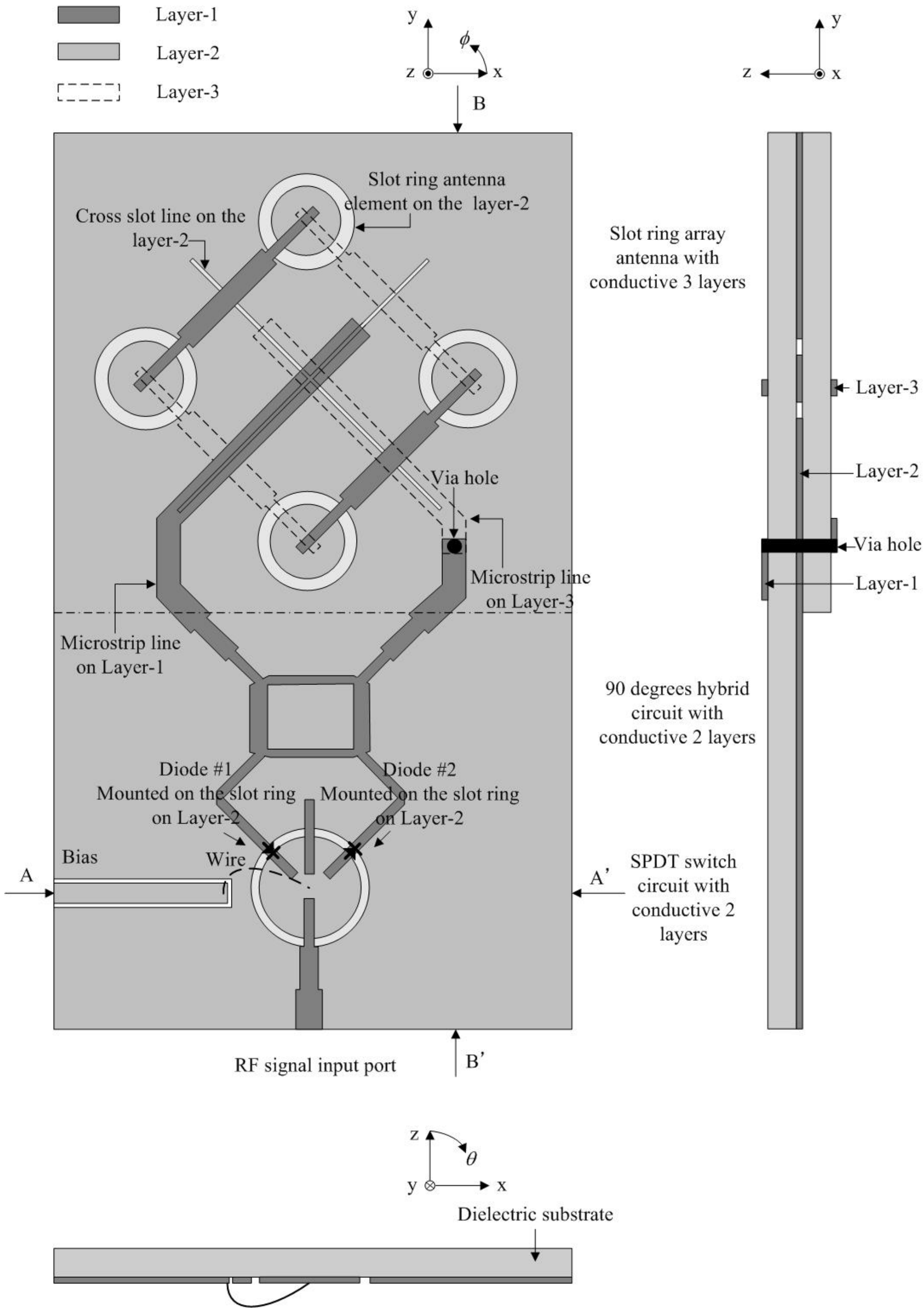


Figure 6.2 Structure of the circular polarization switchable ring-slot array antenna

The configuration and basic operation of the integrated feed circuit is explained in next section.

6.2.3 Microstrip Branch Line Hybrid Circuit with SPDT Switch Circuit

The structure of the feed circuit is shown in Figure 6.3. The feed circuit consist a conventional microstrip Branch line hybrid circuit and a SPDT switch circuit. In this feed circuit, the SPDT switch circuit is designed with 1 layer dielectric substrates and 2 conductive layers.

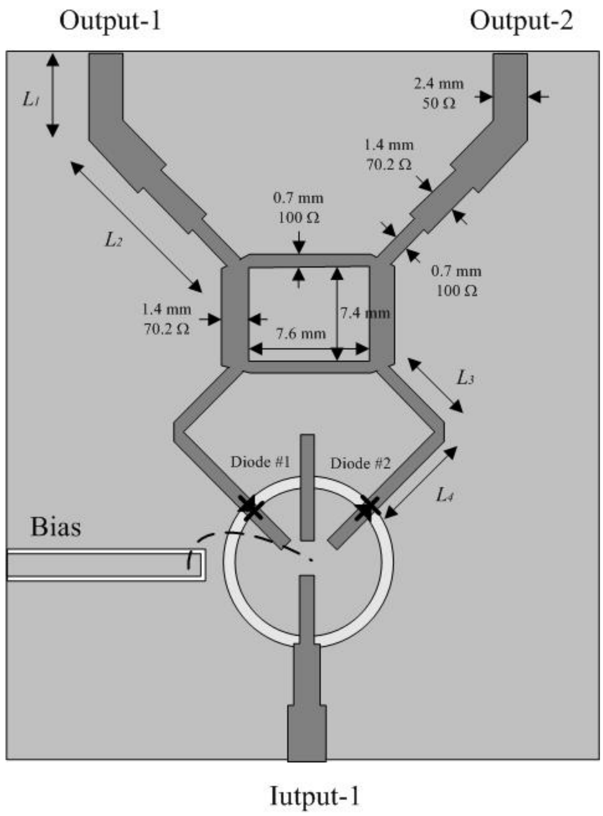
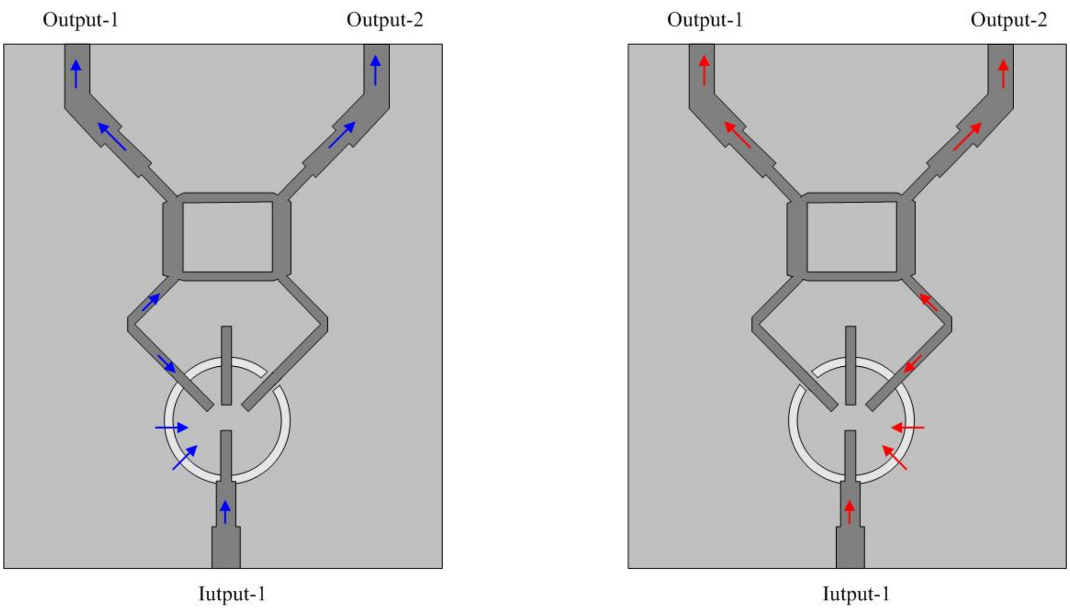


Figure 6.3 Structure of the feed circuit

The SPDT circuit consists of a two wavelength ring-slot on layer-2, microstrip lines on layer-1, and two Schottky barrier diodes mounted on the ring-slot. The switching bias is supplied to the switching diodes through the conductor wire connected to the coplanar waveguide. A 1/2 wavelength open stub microstrip lines on layer-1 is used in the switch circuit to isolate the two output ports. As shown in Figure 6.3, two Schottky barrier diodes are loaded on the ring-slot at ±135 degrees with respect to the input microstrip line (Input-1). The parameters and basic behavior of this is same to the three layers SPDT switch circuit described in chapter 5.

The parameters of the 90 degrees branch line hybrid circuit are shown in Figure 6.3. The basic behavior of the proposed feed circuit is shown in Figure 6.4. When a positive voltage is applied to the inner conductor of ring-slot, the diode #2 is ON, and the diode #1 is OFF. In this condition, the switch circuit transmits the RF signal to the branch line hybrid circuit as shown in Figure 6.4 (a). Then, the RF signal from the switch circuit is divided to two output ports with 90 degrees phase difference in series. When the polarity of the bias voltage applied to the diode is reversed, the switch circuit transmits the RF signal to the branch line hybrid circuit as shown in Figure 6.4 (b). In this case, two RF signals with -90 degrees phase difference can be obtained from this feed circuit.



(a) (b)

Figure 6.4 Schematic electric field of the feed circuit
(a): Diode #1 OFF, Diode #2 ON (b): Diode #1 ON, Diode #2 OFF

Therefore, the ±90 degrees phase difference of the two output RF signals can be switched easily.

In order to analysis the performance of the integrated feed circuit. The SPDT switch circuit and the 90 degrees branch line hybrid circuit are simulated by ADS, respectively.

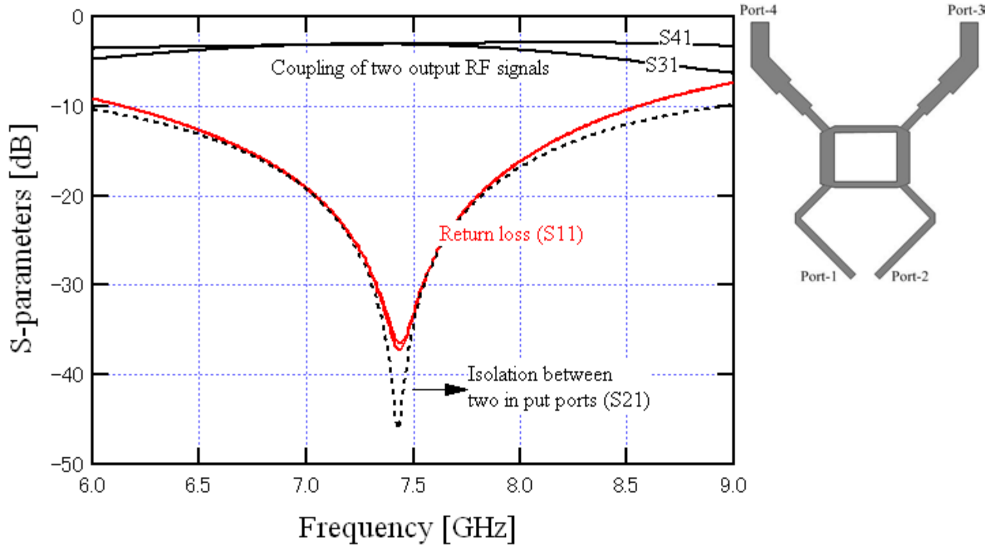


Figure 6.5　S-parameter of the 90 degrees branch line hybrid circuit

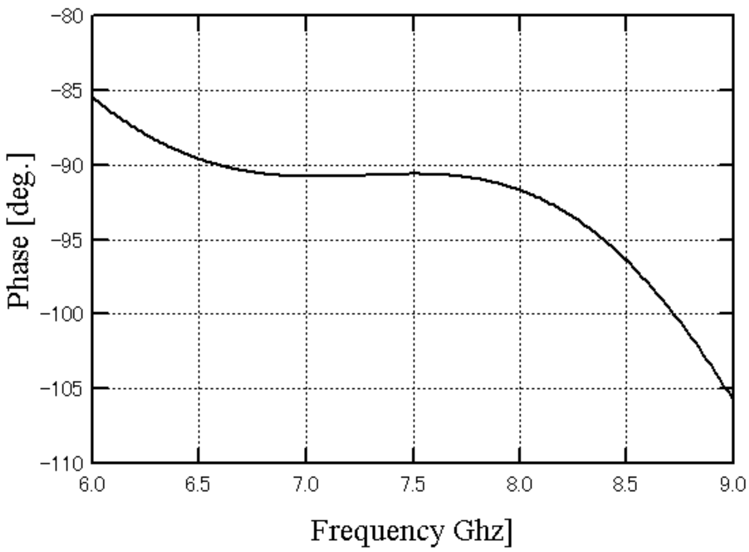


Figure 6.6　Phase difference of the branch line hybrid circuit

Figure 6.5 shows the S-parameters of the branch line hybrid circuit. The design frequency of the branch line hybrid circuit is 7.5 GHz. The simulation model is shown in the side of the Figure 6.5. The return loss is better than -20 dB in the frequency range of 7 GHz to 7.8 GHz, and the isolation between two input ports is better than -20 dB. The insertion loss is less than 1 dB in a wide frequency bandwidth. As Figure 6.6 shows, the 90 degrees phase difference is obtained in from 6.6 GHz to 7.7 GHz. Therefore, the 90 degrees branch line hybrid circuit is successfully confirmed.

The two conductive layers SPDT switch circuit is also simulated by ADS. Figure 6.7 shows the S-parameters of the circuit. The isolation between Port-2 and Port-3 is better than 20dB in a wide band. The -10 dB return loss is obtained in the frequency range of 6.5 GHz to 8.7 GHz. The better insertion loss is obtained in the same frequency band.

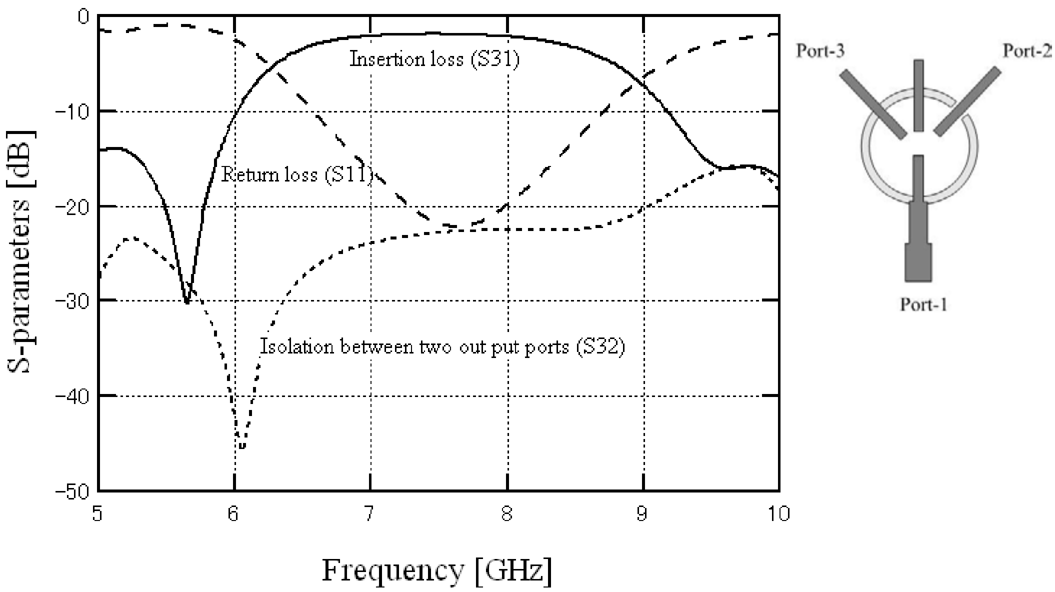


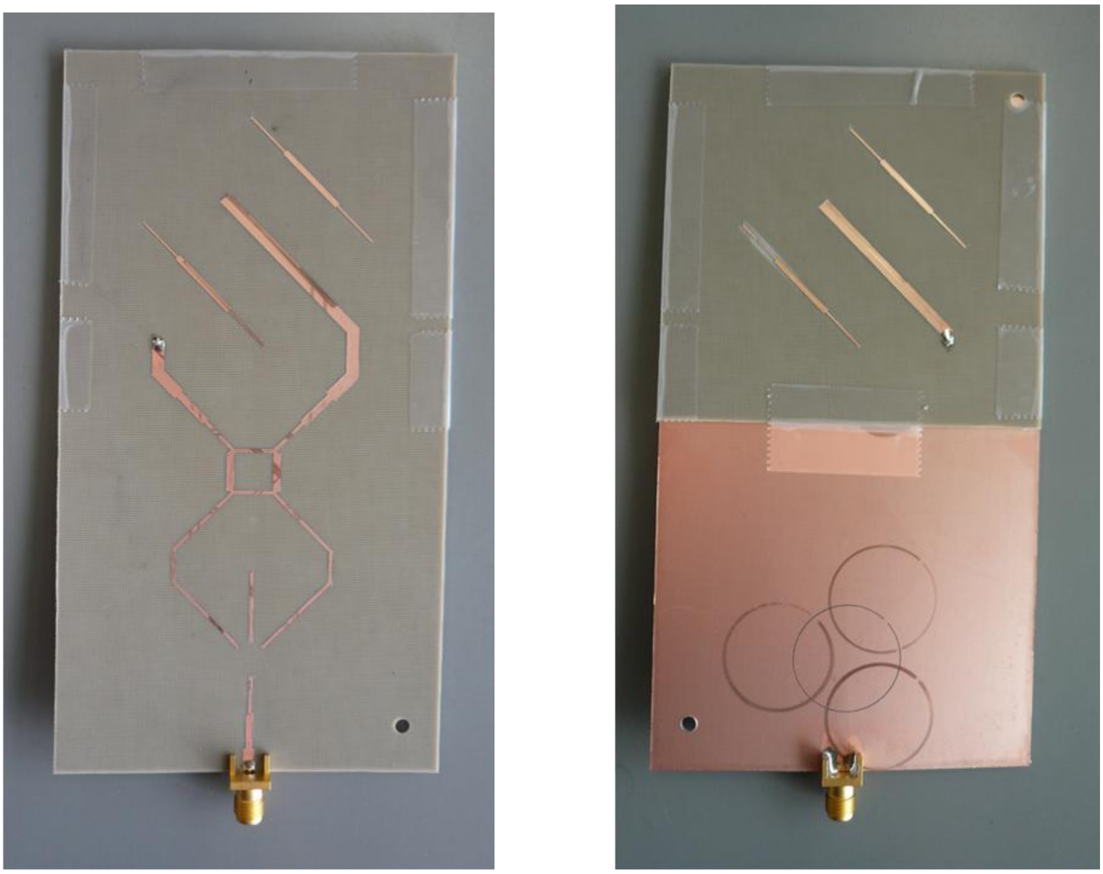
Figure 6.7 S-parameters of the SPDT switch circuit

According to these results above, better circuit performance of the proposed feed circuit is confirmed theoretically.

6.3 Experimental Results

The fabricated ring-slot array antenna is shown in Figure 6.8. The size of the antenna ground plane is 120 mm × 80 mm. The antenna is fabricated on a Teflon Glass Fiber with relative dielectric constant ε_r of 2.15. The thickness of the substrate is

0.8 mm. The antenna performance is measured through the experiment using an Agilent Network Analyzer 8510C in an anechoic chamber. A linear polarization horn antenna is used to measure the proposed antenna. The horn antenna is set at a distance of 2 m from the proposed antenna. The proposed antenna is located on a turn table.



(a) (b)

Figure 6.8 Photos of the fabricated ring-slot array antenna
(a): Top view (b): Bottom view

Figure 6.9 shows the return loss of the proposed ring-slot array antenna. In the experiment, the ON state diode (diode #2) is replaced by a conductor line. The return loss better than -10 dB is obtained in the frequency range over 6.9 GHz to 8.7 GHz, corresponding to about 23% respect to 7.9 GHz.

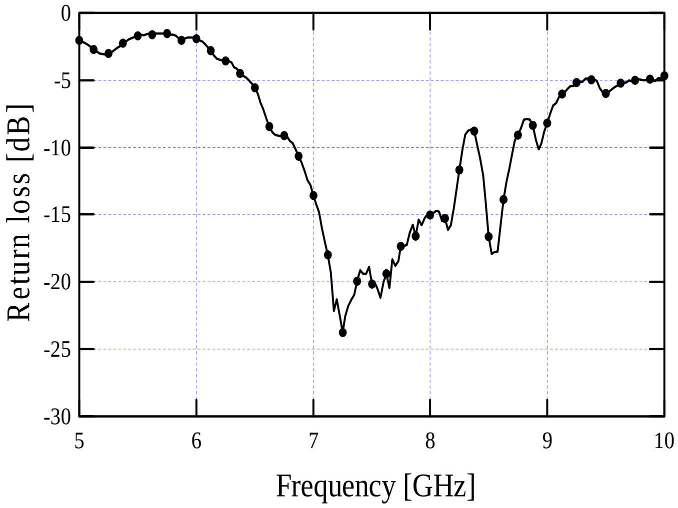


Figure 6.9 Measured return loss of the ring-slot array antenna.

The axial ratio performance is also good. Figure 6.10 shows the axial ratio (AR) of the RHCP, the 3 dB axial ratio bandwidth is 12% respect to 7.55 GHz.

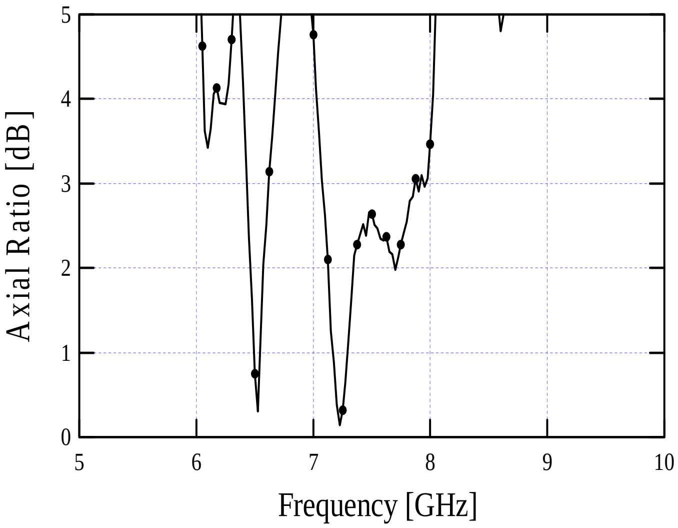


Figure 6.10 Measured axial ratio (AR) of the ring-slot array antenna

Figure 6.11 shows the orthogonal linear polarization components of RHCP. The horizontal plane of the horn antenna is *xz*-plane, and the vertical plane of the horn antenna is *yz*-plane. Both the horizontal (*xz* plane) and the vertical (*yz* plane) linear polarization components are presented, and the two components are almost same. Therefore the circular polarization is confirmed experimentally. Need less to say, the LHCP can also be achieved by change the diodes state.

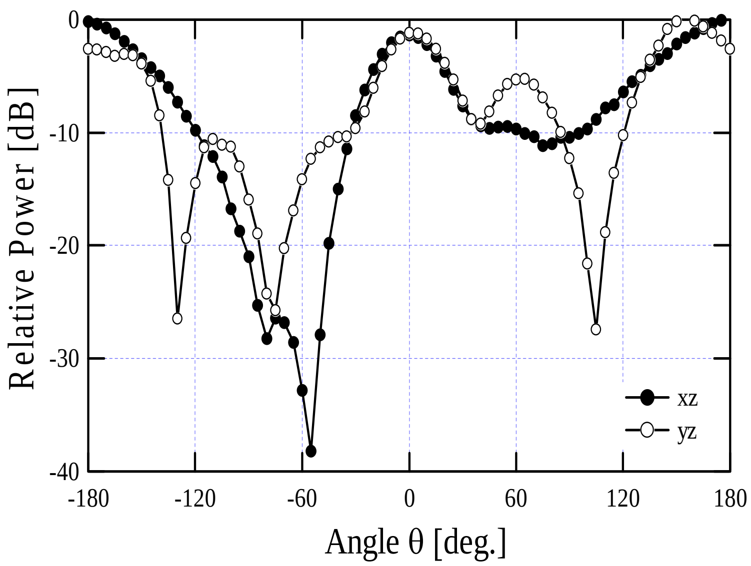


Figure 6.11 Radiation pattern of the ring-slot array antenna, RHCP
Frequency: 7.2 GHz

The experiment results for the proposed circular polarization switchable ring-slot array antenna show a good polarization performance and broad bandwidth in this chapter. The broadband performance is obtained mainly due to the use of the ring-slot antenna elements and the Both-Side MIC technology. The good polarization performance is realized by the symmetrical antenna structure.

6.4 Conclusion

In this chapter, a broad-band circular polarization switchable ring-slot array antenna is described. A ring-slot array, a 90 degrees branch line hybrid circuit and a SPDT switch circuit are integrated in the proposed antenna. Due to the controlling the diodes state, the two kinds of circular polarization, that is, RHCP and LHCP can be switched successfully. The excellent circular polarization performance can be obtained in a wide frequency bandwidth. In addition, the antenna structure is very symmetrical, and the antenna design is very simple.

Therefore, this type of array antenna is useful for wireless communication systems, which involve circular polarization. Moreover, extending this array antenna structure, sixteen elements array or thirty-two elements ring-slot array antenna with circular polarization switching function can be easily realized as well.

Chapter 7

Conclusion

In this thesis, four kinds of array antennas with polarization agility and broadband performance are proposed. The both-sided MIC technology is effectively employed in forming these polarization agile planar antennas. These planar array antennas need no impedance matching circuit in principle and have a very simple antenna design.

A novel 3 conductive layers 2×2 ring-slot array antenna is designed and utilized to realize the simultaneous use of the orthogonal linear polarizations. Due to the use of the characteristics of the ring-slot array antenna and features of the both-sided MIC technology, excellent performances such as broad-band, good isolation, and better cross polarization suppression are obtained. For the symmetrical antenna structure, two orthogonal linear polarizations can be realized with same radiation pattern and same polarization performance. In addition, the antenna design is very simple, and the array antenna is easy to fabricate.

Using the characteristics of the ring-slot array antenna mentioned above, a novel circular polarization ring-slot array antenna with simultaneous use of the orthogonal polarizations is proposed. By integrating a broad-band 90 degrees hybrid circuit, the array antenna can radiate two kinds of circular polarizations; that is, Left Hand Circular Polarization (LHCP) and Right Hand Circular Polarization (RHCP) with good polarization performance. Moreover, the circular polarization can be obtained in a very wide frequency range. The 3 dB axial ratio bandwidths are wider than 25% (RHCP) and 29% (LHCP) and the impedance bandwidth is 47%.

And then a novel linear polarization switchable 2×2 ring-slot array antenna structure has been successfully developed. Basing on the study of three conductive layers ring-slot array antenna, a SPDT switch circuit is integrated in the array antenna to compose an advanced array antenna, linear polarization switchable array antenna. By using the SPDT switch circuit, the antenna can provide the switching function between the ϕ = +45 degree and ϕ = -45 degree linear polarization. In this array antenna, ±45 degree linear polarizations can be realized with excellent cross polarization suppression better than -20 dB.

In addition, a 90 degrees branch line hybrid circuit and a SPDT switch circuit are integrated in the ring-slot array antenna to form a novel circular polarization switchable ring-slot array antenna. The two kinds of circular polarizations (RHCP and LHCP) can be switched with simple method. And the orthogonal circular polarization switchable ring-slot array antenna is theoretically and experimentally verified.

The four kinds of polarization agile slot array antennas are realized for the first time as far as the author knows. These results are very promising and suited for wireless communication systems, RF sensors and radars, which need the orthogonal polarization agility.

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